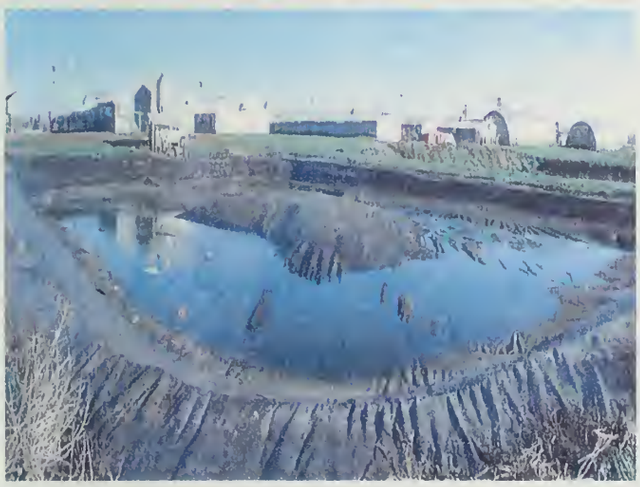

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Swine Odor and Manure Management

December 11-12, 2003
Champaign, Illinois

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PREFACE

Swine Odor and Waste Management was from 1998 to 2003 a Strategic Research Initiative of the State of Illinois Council on Food and Agricultural Research.

The objective of the Initiative was: *To support continued development of an environmentally sustainable, socially acceptable, economically viable U. S. swine industry through a broad, integrated research program addressing issues of swine odor and manure management.*

- State funding made it possible for participating scientists with 11 Illinois institutions and agencies to leverage an additional $10 million in support from external sources.
- Researchers engaged in 29 scientific projects generally categorized as measuring odors, characterizing odor emissions from swine facilities, storing and processing swine manure, nutrition issues, and social and legal issues.
- These pursuits resulted in invention and development of numerous processes, devices, and recommendations, which were communicated to scientific and educational communities by over 150 articles in various media, as well as information of direct and immediate use to producers, which was communicated to them in several ways.
- At the 2003 University of Illinois Pork Industry Conference, highlights of the results of the Initiative will be presented by Initiative researchers in context of the current national and international status of these issues, to be outlined by national and international authorities on the various facets of the topic.

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Overview of Social Issues Related to the Swine Industry

Robert E. Mikesell[1], Kenneth B. Kephart[2], and Charles W. Abdalla[3]

INTRODUCTION

The past 20 years have resulted in significant financial and structural changes in the US swine industry. Production contracts, vertical integration and industry consolidation have been the forces behind these changes, not the least of which is an increase in the size and scale of swine producing facilities. The apparent shift away from independent pork production, on what rural residents often refer to as "family farms," creates concerns about the ownership arrangements and the implications for corporate trends in agriculture. In addition, the increased number of animals and amounts of manure produced raises the potential for conflict.

The primary sources of concern relative to swine production, are as follows:

- Odors, dust and various volatile compounds emitted from the production facilities or from the land application of manure.
- Nutrients and pathogens present in the manure and their potential impact on surface and ground water quality.
- Heavy demand for drinking and wash water in large facilities, and its impact on the local aquifer.
- Noise, flies and other nuisance factors.

As a result of these issues, neighbors often believe that the presence of large swine facilities negatively affects *quality of life, public health, and property values and the local economy.*

Pennsylvania may be unique in terms of its style and location of hog production. Our major hog producing county is Lancaster with an inventory of 339,300 hogs (NASS, 2002); it also ranks 6th in the state for human population (474,601) (US Census Bureau, 2001). Compare this to Henry County, IL with an inventory of 279,000 hogs (NASS, 2002) and a human population of 50,773 (US Census Bureau, 2001). In recent years high land prices and limited access to cropland for manure application in Lancaster County have moved most new swine facility construction to more rural counties. Despite this shift to less densely populated areas, we observe conflict with greater intensity and frequency, particularly during the proposal/permit application stage, in these rural counties compared to that of Lancaster County. For example, Tioga and Bradford counties, located in northern Pennsylvania, have seen increases in hog inventories of 6 to 10 fold over the past 10 years (5,700 to 32,100 and 3,000 to 37,900, respectively). Collectively, the human population in these counties is only about 104,000 (US Census Bureau, 2001). It's not clear why the level of concern is higher in these rural counties; it may be related to the novelty of intensive animal agriculture as well as the abundance of negative reports about swine production. See Figure 1.

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[2] Professor of Animal Science, Pennsylvania State University. Presenter.
[3] Associate Professor of Agricultural Economics.

Impacts on Quality of Life

MacCannell (1988) reported that increased farm size (acres), farm sales, and mechanization all negatively affected community conditions by decreasing median family income, increasing poverty rate, and reducing retail sales. Rural residents perceive environmental risks to be higher for the larger farms, fearing a single, large scale, catastrophic environmental event more than multiple, small-scale events (Thompson, 1997).

For obvious reasons, quality of life is also related to odor. A survey of residents of Lancaster County, Pennsylvania indicated that 57% of respondents who complained about any aspect of a neighboring farm complained about odor (Jones et al., 1998).
Surprisingly, seventy two percent the participants in this study who complained about neighboring farms had direct family ties to agriculture.

Mikesell (2002) asked neighbors of eight swine operations to rate the impact of the local swine operation on neighborhood quality of life. Over one third of the 234 respondents frequently modified their outdoor plans because of odor from the local facility. More than 25% of respondents frequently complained to neighbors or friends about odors from the local facility, and over 18% frequently decided not to invite friends to visit because of facility odor. More than 20% frequently wished they lived elsewhere because of the local swine facility (Table 1).

In the same study, neighbors were asked to record a subjective odor score at their home score each evening between 1800 and 2400 during a 6-week period (0=no odor...5=intense odor). As expected, the neighbors' location (both distance and direction from the swine unit) impacted the intensity of reported odor. In general, neighbors closer to the swine facility recorded higher scores than those more distant. Neighbors to the East and South recorded higher scores than those living to the West and North. But there were also personal factors that significantly affected perceived odor intensity, including:

1) Whether the neighbor knew the operator/manager of the swine facility was related to the reported odor level. In general, the more the neighbor was acquainted with the swine producer, the lower the odor scores.
2) The more "attractive" the farm was perceived to be, the lower the odor scores.
3) As the neighbors' self-reported health rating increased, odor scores decreased.

Including the factors described above in a regression model accounted for about 33% of the variation in average odor scores.

There were also personal factors that had little or no impact on odor scores. These included: income, gender, age, education, whether the neighbor had been raised on a farm, length of time the neighbor had lived there, and the neighbor's reported knowledge of swine production.

Many neighbors commented on their odor diary cards that the intensity of odor during the study was lower than normal because the swine producer was not spreading manure. Cooperating producers had been asked to postpone manure spreading until after the project so that the impact

of the buildings and/or storages could be evaluated alone. While the comments on manure spreading were unexpected, they do reinforce the concept that land application of manure may generate more odor complaints than the buildings or manure storage facilities.

In a North Carolina study, Wing and Wolf (2000) compared quality of life as indicated by the number of times residents could go outside or open their windows. Three communities were selected: one near a 6000–head hog operation, the second near two intensive cattle feeding operations, and a third with no livestock operations within a two mile radius. Over 50% of residents living near swine operations reported that odor prevented them from opening windows or going outdoors on more than 12 occasions within the past year, compared to less than 15% of those living near a cattle operation, neighbors or non-neighbors.

Impacts on Public Health

Water pollution from accidental manure spills, application run-off, storage facility structural failure, and illegal discharge are all potential threats to groundwater. In Pennsylvania's Lower Susquehanna River Basin, about 30% of sampled wells and about 20% of sampled stream contained more than 10 mg/l nitrate-nitrogen. The major identified source of nitrate-nitrogen was animal manure used as agricultural fertilizer (Lindsay et al., 1998). Although relatively few incidents have been reported, drinking water containing high concentrations of nitrate can lead to methemoglobinemia (blue-baby syndrome) (Fan and Steinberg, 1998).

Airborne emissions can affect health through direct irritant and psychophysiologic processes (Schiffman, 1998). Health effects on swine farm workers from odorous compounds and dust have been well documented (Donham, 1990; Reynolds et al., 1996; Cole et al., 2000), and are more prevalent than those reported by grain farmers and control subjects (Dosman et al., 1997). Typical symptoms include respiratory irritation, cough, phlegm production, chest tightness, eye irritation, headache, nausea and drowsiness. Four mechanisms for symptoms have been suggested: 1) toxicological effects of volatile organic compounds (VOCs, intermediate volatile gasses generated by anaerobic decomposition of manure); 2) direct irritation of the eyes, nose, and throat; 3) VOC stimulation of sensory nerves causing neurochemical effects that influence health; 4) emotional factors that bring about symptoms. Schiffman (1998) suggested that the cause of physical symptoms is probably a combination of these mechanisms.

Donham et al. (1995) reported that the correlation between pulmonary function and exposure is highest after 6 years' exposure. Reynolds et al. (1996) suggested that dust may an important factor related to chronic changes in pulmonary function whereas endotoxins are associated with acute health affects. Reynolds et al. (1997) reported that dust, endotoxins, hydrogen sulfide, and ammonia levels 60 meters downwind from swine operations were generally below detectable limits, except ammonia, which ranged from 0.01 to 0.46 ppm and was measured at significantly higher concentrations than those upwind.

Thu et al. (1997) compared health and quality of life issues for people (n=18) living within two miles of a single large-scale swine farm and found that swine farm neighbors reported more respiratory symptoms than control subjects (n=18). In a recent review, Thu (2002) provided

evidence that the health symptoms, which are well documented among swine workers, closely parallel those reported by neighbors of large swine operations.

Wing and Wolf (2000) interviewed North Carolina swine farm neighbors (n=55) and non-neighbors (n=50) regarding physical symptoms over the previous six months. Neighbors reported episodes of headache, runny nose, sore throat, nausea, diarrhea, and burning eyes at frequencies generally two fold higher than that of non-neighbors.

In 1995, Schiffman et al. reported that neighbors (n=44) of swine operations were more tense, more depressed, angrier, less vigorous, more tired and more confused than control subjects (n=44) who did not live near swine operations.

Mikesell (2002) discovered that neighbors (n=234) of commercial swine operations and non-neighbors (n=107) who lived in similar rural areas had nearly identical self-reported health scores (1.9 vs 1.9 on a scale of 1=very healthy...5=not at all healthy). Neighbors, however, reported more frequent incidence of nausea, fatigue, and throat irritation ($P < .05$) than did non-neighbors (Table 2). When demographic differences were controlled, there were no significant differences between the two groups in regard to frequency of cough, headache, muscular aches, or chest tightness (Table 2). Neither depression nor anxiety were different between the two groups, supporting the findings of Thu et al. (1997), but not those of Schiffman et al. (1995).

Impacts on Property Values and the Local Economy

Neighbors of large swine operations often comment that property values will be reduced because of proximity to the farm and its associated odors. A Michigan study of home values concluded that every additional hog found within a five-mile radius resulted in a decline in residential property value of $0.43. Homes located near larger operations were impacted proportionally more than homes located at a greater distance (Abeles-Allison and Connor, 1990). In 1997, Palmquist found that North Carolina home values declined by 4.75 and 0.56 percent if a 2400 head finishing building were constructed 0.5 or two miles away, respectively. Missouri data indicate that farmland prices were reduced an average of $58 per acre when located within two miles of a swine farm (Seipel et al., 1998).

However, a Minnesota group studied the values of 292 rural residential properties within 3 miles of feedlots (including swine and other livestock) housing over 500 animal units (AU). Results indicated that rural property values were positively influenced by nearby feedlots (Taff et al., 1996).

A recent study (Ready and Abdalla, 2003) in Berks County, Pennsylvania indicated that landfills, airports, mushroom facilities and large livestock operations have negative impacts on property values. An implicit house price function was estimated based on 8,090 single family houses sold between 1996 and 2002, using regression analysis. Information on surrounding land use, proximity to local disamenities, and structural attributes of the houses were used to explain variation in house prices. Only the results for several potential local disamenities are presented here. Details and additional results can be found in Ready and Abdalla (2003) (http://landuse.aers.psu.edu).

The potential local disamenities examined in the study were landfills, larger animal production facilities, mushroom production facilities, sewage treatment plants, high traffic roads and a regional airport. Animal operations studied included dairy and beef cattle, swine and poultry. Larger animal facilities were defined as those greater than 200 Animal Equivalents Units (AEUs) defined in Pennsylvania's Nutrient Management Act (Beegle et al, 1987). The study defined "larger" facilities as dairies with more than 155 cows, beef operations with more than 175 cattle, swine operations with more than 1380 finishing hogs, and poultry operations with 85,300 broilers.

Several local disamenities were found to have a negative impact on nearby house prices. A landfill located 800 meters from a house decreases that house's value by an estimated 6.9%. The impact of a large-scale animal production facility on house price was about two thirds as large as that of a landfill (4.1% at 800 meters). The impacts on house price from mushroom production and from the regional airport were much less (0.4% and 0.2%, respectively, at 800 meters). The impact from high-traffic roads was small, and extended only a short distance. No significant impact was found for sewage treatment plants.

Additional analysis attempted to investigate whether different types of animal production facilities had different impact on nearby house prices. Differences in the impact due to differences in the size of the operation (number of AEUs) were not statistically significant. Further, medium-sized production facilities (200 to 300 AEUs) were found to have a statistically significant negative effect on house prices when considered apart from larger facilities. Similarly, the impact did not vary significantly by species (poultry, swine, and beef/dairy). An analysis of proximity of animal production facilities and residential properties showed that the density of single family homes around animal production facilities was lower than the average for rural parts of the county, which had the effect of reducing the potential for conflicts.

The total impact on surrounding house prices was calculated for a landfill, the regional airport, and an animal production facility. The average impact of a single animal production facility on 119 single-family residences located within 1600 meters of the facility $1,803. The total impact on all 119 houses is $214,589, or 1.7% of the assessed value of the affected houses. These figures are intended as illustrations, and should not be considered averages for similar facilities. The impact from any given animal production facility will depend on the number of houses located near the site, and on the market value of those houses absent the facility.

These estimates capture only those impacts that fall on residents who live near the facilities. They do not include costs of impacts that occur farther from such facilities, such as impacts on downstream water quality, or positive or negative amenity impacts on tourists or commuters who travel past such facilities. Until more research is conducted in more counties, care should be taken in extrapolating the results from this research to other regions. At this time, the authors have no reason to expect ahead of time whether the impact of animal production facilities on house prices will be the same, larger, or smaller in other counties.

Martin and Zering (1997) listed employment opportunities as a significant economic benefit to rural communities hosting intensive pork production facilities. Otto (1998) reported that a new

3400-sow farrow to finish facility provides 40 direct and indirect jobs, and generates nearly $1 million in employee income per year. Additionally, contract production is a source of alternate farm income for small family farms (Martin and Zering, 1997).

Neighbors of large scale-swine operations often argue that the costs to a township's infrastructure (roads, etc.) are not sufficiently offset by the taxes paid by large-scale swine operations. Abeles-Allison and Connor (1990) estimated township benefit:cost ratios for 500 and 5000 head finishing operations to be 5.64 and 3.86, respectively. State tax revenues were expected to increase by $65,000. Martin and Zering (1997) noted significant tax benefits for communities near intensive swine production.

SUMMARY

Rural residents often believe, and some evidence suggests, that the proximity of commercial swine enterprises will negatively impact quality of life, personal health and property values. These impacts are probably effects of, or concerns about 1) odors and other emissions from the swine facility or land-applied manure; 2) nutrients and pathogens present in manure that could alter surface and ground water quality; 3) water draw-down from local aquifers; 4) Noise, flies and other factors.

Our industry has aggressively responded to these concerns through the development and implementation of educational programs, and research funding. Effective solutions to these issues problems are slowly beginning to emerge, but there are a variety of personal factors that comprise an individual's perspective and there is mounting evidence that public health maybe affected by the presence of a swine operation. Hence, it may be years before swine producing systems can be successfully developed and adopted that are deemed acceptable to the concerned neighbor.

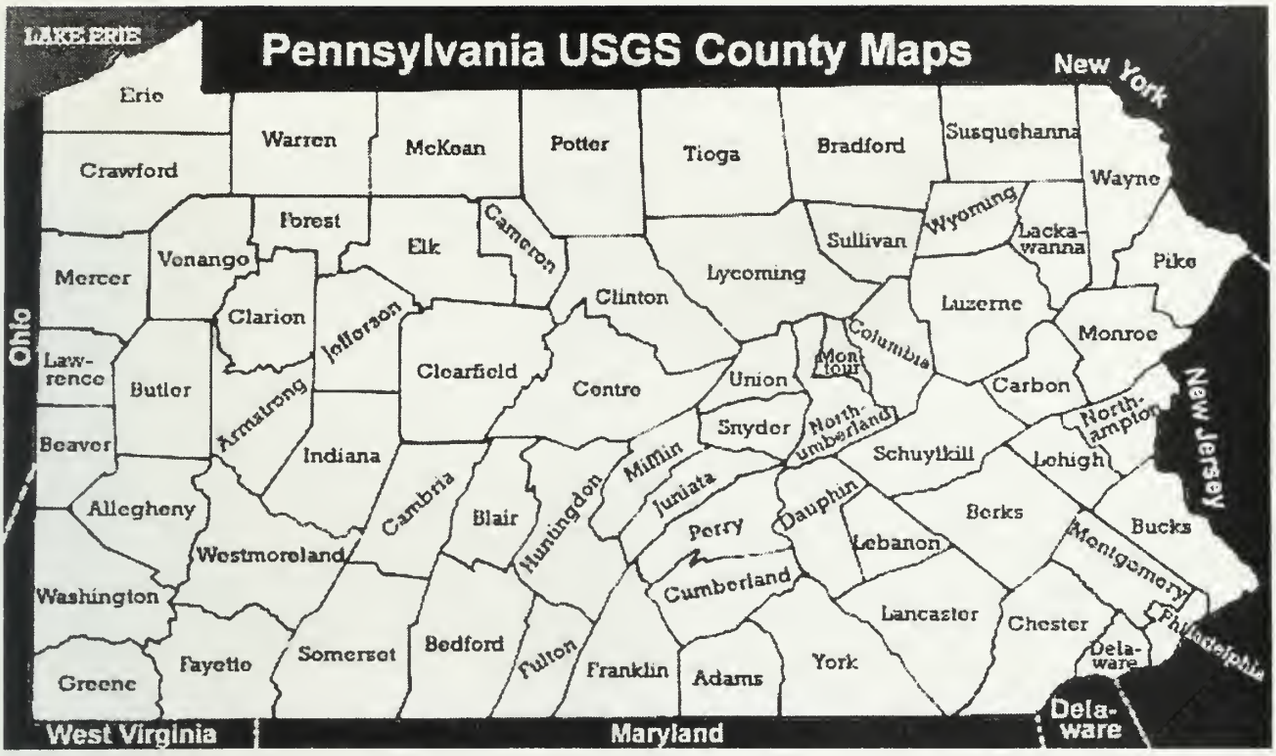

Figure 1: County map of Pennsylvania

Table 1. Responses to eight statements regarding the impact of a neighboring swine operation in Pennsylvania on quality of life. [a]

Statement	Neighbor Response (%) Never/Rarely [b]	Occasionally	Frequently
a. I expressed concern to the operator of the facility about the odor coming from it.	82.9	13.0	4.2
b. I modified my outdoor plans because of the odors from this facility.	45.2	20.7	34.1
c. I decided not to invite friends to visit because of the odor from this facility.	64.1	17.5	18.4
d. The odor from this facility made me ill.	82.5	11.3	6.1
e. I complained to one or more neighbors or friends about the odor emanating from this facility.	49.8	22.6	27.6
f. I participated in a group or community meeting protesting the odor from this facility.	83.1	9.9	7.0
g. I've wished I didn't live in this location because of the swine facility.	63.4	16.0	20.7

[a] Survey instrument contained the following wording. "Now consider how, if at all, the *large-scale swine operation located near your home* has impacted you and your lifestyle. Indicate how *often* you have experienced each of the following *in the past year*." Adapted from Robert E. Mikesell PhD dissertation. 2002. Odor remediation and siting considerations for Pennsylvania swine farms. The Pennsylvania State University.

[b] Never and Rarely responses were combined.

Table 2. Comparative frequency of reported health symptoms between neighbors of one of eight swine operations in Pennsylvania and non-neighbors living in similar, rural areas. [a]

	Neighbors (%)		Non-neighbors (%)			
Symptom	0 to 5 times [c]	> 6 times [c]	0 to 5 times	> 6 times	Model P	Contrast [b] P
Cough	73.3	26.7	82.0	18.0	.36	-
Nausea	79.5	20.5	93.9	6.1	<.01	.01
Headache	48.3	51.7	59.8	40.2	.02	.28 [d]
Muscular aches	48.5	51.5	52.0	48.0	.70	-
Chest tightness	83.1	16.9	89.8	10.2	.27	-
Fatigue	49.3	50.7	64.0	36.0	.02	.03
Throat irritation.	67.3	32.7	82.8	17.2	.01	.03
Depression	85.2	14.8	87.8	12.2	.58	-
Anxiety	83.8	16.2	87.6	12.4	.66	-

[a] Survey instrument contained the following wording. "How often in the last year have you experienced each of the following symptoms?"
Adapted from Robert E. Mikesell PhD dissertation. 2002. Odor remediation and siting considerations for Pennsylvania swine farms. The Pennsylvania State University.

[b] Comparisons were controlled for three demographic variables that differed between neighbors and non-neighbors: gender, area of residence, and history of farm residence.

[c] Zero and 0 to 5 responses were combined. Six to ten and > 10 responses were combined.

[d] Headache differed significantly for "gender". Females had more frequent incidence of headache than males (P = .03).

REFERENCES

Abeles-Allison, M. and L. J. Connor. 1990. An analysis of local benefits and costs of Michigan hog operations experiencing environmental conflicts. Agricultural Economics Report Number 536. Michigan State University.

Beegle, Douglas. B. 1997. "Pennsylvania's Nutrient Management Act: Who Will Be Affected?" Pennsylvania State University Agronomy Fact Sheet #54, 4pp.

Cole, Dana, Lori Todd, and Steve Wing. 2000. Concentrated swine feeding operations and public health: A review of occupational and community health effects. Environ Health Perspect 108: 685.

Donham, K. J. 1990. Health effects from work in swine confinement buildings. Am. J. Ind. Med. 17:17.

Donham, K., S. Reynolds, P. Whitten, J. Merchant, L. Burmeister, and W. Popendorf, W. 1995. Respiratory dysfunction in swine production facility workers: dose-response relationships of environmental exposures and pulmonary function . Am J Ind Med 27:405.

Dosman, J. A., A. Senthiselvan, E. Barber, S. Kirychuk, C. Rhodes, L. Holfeld, Y. Zhang, T. Cormier, and T. Hurst. 1997. Lung function measurements in swine confinement workers: longitudinal declines, shift changes, environmental intervention. In Livestock Environment V, Proc. 5th Int. Livestock Environ. Symp. pp.15-16. ASAE Pub. St. Josephs, MO.

Fan, A.M. and V. E. Steinberg. 1996. Health implications of nitrate and nitrite in drinking water: an update on methemoblobinemia occurrence and reproductive and developmental toxicity. Regul Toxicol Pharmacol 23:35.

Jones, K., T. W. Kelsey, P. A. Nordstrom, L. L. Wilson, A. N. Maretski, and C. W. Pitts. 1998 Neighbors' perceptions of animal agriculture. Staff paper #322. Penn State University, University Park, PA.

Lindsay, B. D., B. D. Breen, M. D. Bigler, and R. A. Brightbill. 1998. Water Quality in the lower Susquehanna river basin, Pennsylvania and Maryland, 1992-1995.Water Resources Investigation Report WRIR 97-4146. Available at http://pa.water.usgs.gov/pa_pubs.html Accessed November 6, 2003.

MacCannell, D. 1988. Industrial Agriculture and Rural Community Degradation. In Agricultural and Community Change in the U.S.: The Congressional Research Reports. L. E. Swanson, ed. pp 15-75. Westview Press, Boulder, CO.

Martin, L. L., and K. D. Zering. 1997. Relationship between industrialized agriculture and environmental consequences: the case of vertical coordination in broilers and hogs. J. Ag. Appl. Ec. 29:45.

Mikesell, R. E. 2002. Odor remediation and siting considerations for Pennsylvania swine farms. Thesis. Doctor of philosophy. The Pennsylvania State University.

National Agriculture Statistics Service (NASS). 2002. Pennsylvania livestock group. http://www.nass.usda.gov:81/ipedb/. Accessed November 4, 2003.

Otto, D., P. Orazam, and W. Huffman. 1998. Community and economic impacts of the Iwoa hog industry. In: Iowa's Pork Industry: Dollars and Scents. Available at http://www.econ.iastate.edu/outreach/agriculture/livestock/pork/dollars_and_scents/. Accessed November 4, 2003.

Palmquist, R. B., F. M. Roka, and T. Vukina. 1997. Hog operations, Environmental effects, and residential property values. Land Economics. February.

Ready, Richard C., and Charles W. Abdalla. 2003. "GIS Analysis of Land Use on the Rural-Urban Fringe: The Impact of Land Use and Potential Local Disamenities on Residential Property Values and on the Location of Residential Development in Berks County, Pennsylvania." Staff Paper 364, Department of Agricultural Economics and Rural Sociology, The Pennsylvania State University, University Park, PA. http://landuse.aers.psu.edu

Reynolds, S. J., K. J. Donham, J. Stookesberry, P. S. Thorne, P. Subramanian, K. Thu, and P. Whitten. 1997. Air quality assessments in the vicinity of swine production facilities. J. of Agromed. 4:37.

Reynolds, S. J., K. J. Donham, P. Whitten, J. A. Merchant, L. F. Burmeister, and W. J. Popendorf. 1996. Longitudinal evaluation of dose-response relationships for environmental exposures and pulmonary function in swine production workers. Am. J. Ind. Med. 29: 33.

Schiffman, S. S., E. A. Sattely-Miller, M. S. Suggs, and B. G. Graham. 1995. The effect of environmental odors emanating from commercial swine operations on the mood of nearby residents. Brain Res. Bull. 37:369.

Schiffman, S. S. 1998. Livestock odors: Implications for human health and well-being. J. Anim. Sci. 76:1343.

Seipel, M., M. Hamed, J. S. Rikoon, and A. M. Kleiner. 1998. The impact of large-scale hog confinement facility sitings on rural property values. In Proc. Production Systems and Environment. pp. 413-418.

Taff, S. J., G. G. Tiffany, and S. Weisburg. 1996. Measured effects of feedlots on residential property values in Minnesota: A report to the legislature. Staff paper p 96-12.

Thompson, P. B. 1997. Sustaining animal agriculture and environmental quality in the south: what happened and why? Discussion. J. Ag. And Appl. Ec. 29:73.

Thu, K. M. 2002. Public health concerns for neighbors of large-scale swine production operations. J. Agric. Safety and Health. 8: 175.

Thu, K, K. Donham, R. Zeigerhorn, S. Reynolds, P. S. Thorne, P. Subramanian, P. Whitten, and J. Stookesberry. 1997. A control study of the physical and mental health of residents living near a large-scale swine operation. J. Agric. Safety Health 3:13.

United States Census Bureau. 2001. State and county quick facts. http://quickfacts.census.gov/qfd/ Accessed November 4, 2003.

Wing, S. and S. Wolf. 2000. Intensive livestock operations, health, and quality of life among eastern North Carolina residents. Environ. Health Perspec. 108: 233.

But What Do the Neighbors Think?1

Ann Reisner, Dawn Coppin [Project Manager], and the Pigs in Print Group

Background changes in agriculture

In the 1940s, the US census recorded over 6 million farms in active cultivation. Forty years later, farm numbers had dropped to fewer than 2 million (Albrecht 1998). At the same time, industrial farms – those with 1,000 or more acres – nearly doubled, from 89,000 in 1935 to 173,000 farms in 1992 (Albrecht 1997). Farmers with very large acreages now control the majority of US farmland. In 1935, at 1.3 percent of all farms, industrial farmers controlled around 29 percent of US farmland; in 1992, industrial farms, 9 percent of all farms, controlled slightly less than two-thirds.

Animal agriculture has also radically changed, particularly – for hogs – from the 1980s onwards. The original technological innovations that allowed farmers to move hogs from pasture to full-time confinement – the detailed elaboration of swine's nutritional requirements and the development of the manure lagoons and other schemes that allowed for efficient waste removal – were developed starting in the 1950s. Farmers began moving to partial and full confinement virtually immediately, and the growth of confinement operations grew steadily over the next several decades. However, after the expansion of Murphy Farms in North Carolina (Thompson 2000) in the 1990s, industrialized hog farms quickly spread to the more traditional hog growing states, including Iowa, Minnesota, and Illinois. The growth of these large facilities led to considerable local controversy and protest.

Growth of controversy

Controversy in agriculture is not particularly unusual. From the beginnings of the republic, small farmers have criticized, organized, and protested. As early as the 1780s, small yeoman farmers were organizing to stop farm foreclosures during a severe depression that followed the Revolutionary War. Veteran Daniel Shay's men, who took up arms to stop creditors and courts by force, wore "sprigs of evergreen in their hats, just as they had done during the Revolution ... telling the world that, from where they stood, the war was not over" (Stock, 41).

In the 1800s, following the Civil War, such organizations as the Grange (Patrons of Husbandry) and the Farmers' Alliance actively protested market issues, including the high costs of transporting goods by railroad. Later organizations – the Farmers' Union, the American Society of Equity, and the Nonpartisan League – also addressed the constant marketing and credit problems of producers. At the heart of both waves of farmer protest was a vision of a more egalitarian rural society where the "small guy" could wrestle control from corporations and the federal government and where small producers were valued for what they made rather than what

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1 This paper is a condensed version of a larger work summarized in a report (Pigs and Publics) on the SOMR website (www.traill.uiuc.edu/sowm/). The Pigs and Publics Project is part of the Strategic Research Initiative on Swine Odor and Waste Management. This project is supported by the Illinois Council on Food and Agricultural Research, the University of Illinois Extension, and the College of Agricultural, Consumer and Environmental Sciences Office of Research.

they could buy (Stock, 75). These farm movements made alliances with urban and other rural (e.g., miners) organizations in the populist movement and later as part of the New Deal, but in essence the progressive farm movement and the urban progressives were joined at the most abstract level. The specific goals and activities of the urban progressives – sanitation, child-labor laws, urban parks, union rights – were distinctly different from rural movement concerns and from farming in general.

In the latter half of the 20th century, however, farmers more commonly were the focus rather than the source of social movements – first, environmentalists questioned the effects of DDT on the ecosystem. Then animal rights activists questioned the morality of confinement agriculture. But unlike most of the movements of the latter 20th century, much of the active resistance to large-scale swine farms has been neighbor against neighbor or at least community member versus farmers. Second, similar to the movements of the 19th century, the resistance to large-scale farms is in part structural – the "big" farmers versus the "little guys."

However, unlike earlier farm movements of the 18th and 19th centuries, national-level social-movement organizations – such as the Environmental Defense Fund, Humane Society of the United States, Sierra Club, and others – also actively engaged in the swine-farm controversy. These national organizations bring 20th century urban concerns – environment and animal rights – to the debate on large-scale swine facilities (LSSF) and represent potentially powerful allies for activists in small communities.

Review of earlier studies

Analysis of Illinois newspaper coverage in 22 selected counties isolated 41 arguments supporting LSSF and 32 arguments opposing, running across 6 themes: community impact/location, economy, environment, ethics/morals, farm structure, and legal/regulatory. Each major theme has a number of sub-arguments, which are the specific arguments found almost verbatim in the newspaper articles. The arguments used by proponents of LSSF tend to focus on 1) economics, (2) environment, and (3) legal/regulatory (see Table 2). The arguments used by opponents of LSSF tend to cluster around (1) environment (specifically regarding water and air), 2) farm structure (desire and concern for small-scale farms), and (3) legal/regulatory.

However, pro- and anti-LSSF groups are to some degree talking at cross-purposes. Even across similar themes, those in favor of LSSF and those opposed are addressing different sets of concerns (see Tables 2 and 3). A typical example is the series of statements various newspaper articles had about farm structure. Within this argument theme the people who opposed large-scale swine facilities tended to concentrate on large-scale versus small-scale swine farming. The single most frequently made argument in the farm structure theme was that large-scale swine facilities are bad for small-scale farmers (52 percent), clearly the primary concern regarding structural issues voiced in the newspaper articles. An additional 39 percent simply claimed that large-scale swine facilities were not farms at all – or at least not farms in the traditional sense – and therefore should not be treated as such. The remainder of the opposition arguments based on farm structure reasons (9 percent) concerned claims that small-scale hog farms were better than LSSF and that the large operations were not sustainable over the long-term.

The farm-structure arguments voiced by proponents of LSSF barely address the main points of those opposed to the development of the large-scale swine industry. Three-quarters of the farm-structure arguments put forth by proponents dealt with claims that LSSF are better and easier to manage than small-scale operations, that LSSF attract younger farmers, and that the likelihood of problems depends on the skill of the manager rather than the design of the facility. The rest of the proponent arguments in this theme flatly contradict opponent claims by saying that LSSF are really no different from, and are certainly not bad for, small-scale swine farms.

Based on the frequency of arguments in the newspapers, it appears that the most important reasons to switch to large-scale farming were environmental, ethical, and economic. Advocates argued that large-scale swine facilities would be good for the environment, that the more advanced technologies, more specialized management, and newer facilities would, in fact, be less likely than older facilities to emit odors or leak manure into ground or surface water. Proponents also asserted that they held the ethical high ground: farmers have the right to do whatever s/he want on their own land so long as they operate within the current system of rules and regulations. They maintained that LSSF were necessary for the younger generation to stay in hog farming and that those who opposed such facilities were either jealous or did not know anything about these operations. Those who supported LSSF also pointed out that large farms were better business operations, that they were economically good for the community because they created jobs and added to the tax base, and that LSSF benefited the economy in general.

The legal/regulatory argument theme came second in frequency, but these arguments were not reasons why LSSF were better or ought to be allowed; instead they were claims made in reaction to opponents' challenges that the current laws regulating LSSF were inadequate. The most prominent argument in this theme concerned regulations being bad for the swine industry as a whole, including the small-scale farmers whom the opponents were thought to support. Arguments regarding the community impacts from LSSF were the least frequent, suggesting that either proponent could not think of any or this was not an important theme.

Those people who were opposed to new or proposed hog farm expansion, on the other hand, focused primarily on the potential for environmental impacts (see Table 5). The newspaper articles included 1180 claims, almost one-half of all anti-expansion comments, about the risks that large-scale swine facilities posed for the environment, including air, water, and soil pollution.

The second most frequent argument theme was legal/regulatory (see Table 5). Opponents and proponents were diametrically opposed on this point, with opponents of LSSF arguing that more laws were needed to control the large-scale operations, whereas proponents maintained that current laws were quite adequate and any more would be detrimental to the entire industry. The third greatest concern that opponents expressed in the newspapers concerned the threat posed by LSSF to the structure of the swine industry. In particular, they claimed that LSSF are more akin to industrial factories than to agriculture and that small-scale swine operations are better for the community, the economy, and the environment.

In contrast to the arguments articulated in support of LSSF, a distinct theme underlying a variety of comments was that expansion of hog facilities was disruptive and difficult for communities.

Collectively, sources were concerned about a variety of impacts including the potential for social disruption from the proposed expansion; that expansion went against traditional values, destroyed the community's history, violated ethics of neighborliness, and made people argue and fight. In addition, they were concerned that the community would have to develop infrastructure to handle the impacts of LSSF such as paying for social services, schools, and health care for migrant workers and cleaning up after spills and abandoned lagoons. Those opposed to LSSF also maintained that large-scale operations had no overall economic benefit because they displaced more jobs than they created, decreased property values, and would make alternative industries, such as tourism, less viable.

Newspapers showed a remarkable consistency with the overall arguments presented. The vast majority of the articles that originated at the community level, however, were about controversies centered on initial sitings. There were relatively few stories dealing with controversies following the building of facilities.

When we looked at newspaper articles, we found that almost all of the articles were written before the hog farms were expanded (or built) or in the very early months of farm operation. Once the LSSF were up and running, by and large, there were relatively few articles about routine hog operation.

Since newspaper articles tended to be written before the expansions, the objections that neighbors, activists, and others raised about the operations were about potential rather than actual problems and theoretical rather than existing benefits. It was quite likely that newspaper sources could describe more – and potentially far more – problems and benefits than neighbors or community members actually would have. The concern that newspaper articles were emphasizing only the first stage of hog-farm expansion led directly to the next phase of the project: a survey of what farmers, residents, and other important stakeholders' thought were the main problems and benefits of LSSF several years after the initial news coverage.

Pigs and Publics

Procedures for selecting each group of respondents

Our goal was to compare what newspapers said with what people in the area believed were actual problems ex post facto, so we kept the 22 newspapers and 52 counties the newspapers covered as the basic units of the survey. We selected as survey respondents members of the major stakeholder groups identified in newspaper articles as involved in local controversies over the building of LSSF: farmers who were building new or expanding swine operations, neighbors of these farmers, zoning board officials, and anti-LSSF activists. We also included one or more journalist(s) from each of the newspapers.

- *Farmers* The majority of respondents were selected from an Illinois Department of Agriculture list of farmers who filed a permit to construct or expand their operation in 1998 (Illinois Stewardship Alliance). In five cases, no farmer in the selected county had filed a permit. In these cases, local agricultural extension agents were contacted and

asked to identify a local farmer who operated a LSSF. A total of 52 farmers were identified.

- *Journalists* Journalists were selected based on three criteria. When newspaper stories carried a byline, the journalist(s) who wrote articles on the swine facility were identified directly. If no journalist had covered a story, or if the journalist(s) who had covered the story had left the study newspaper, we first asked the newspaper to identify the person who was assigned to the agricultural beat. If the newspaper did not consider agriculture as a beat, the newspaper managing editor was asked to identify which journalist(s) would be "most likely" to be assigned to cover an agricultural story. A total of 21 journalists were identified as eligible respondents.
- *Zoning officials* These stakeholders were found by contacting officials at the courthouse of the county in which the proposed or existing farm was sited. Here zoning information was available, including zoning ordinances and officials' names. In some less populous counties zoning is not nested in an individual office, but rather is a function of the county board. In these instances the senior-most member of the board was selected. A total of 51 zoning-board officials were identified as eligible respondents.
- *Residents* Residents were found using plat map information of owners and residents of land within a 1.5-mile radius of the operations of selected farmers (identified earlier). Copies of maps were available in the University of Illinois Library as well as at county assessors' offices. Five residents or neighbors were identified for each facility. Family members, primarily identified as those who shared a last name with the subject farmer, were taken out of the pool of eligible candidates for receiving the surveys. A total of 240 residents were identified as eligible respondents.
- *Activists* Names of anti-LSSF activists were found through newspaper articles that had covered controversies over facilities. Those who had spoken at town meetings county board meetings or other community meetings or were representatives of groups such as FARM were identified as activists in their community. Not all newspapers identified activists. In this case, for the county (ies) associated with such a newspaper, no activists were contacted. A total of 31 activists were identified as eligible respondents.

Questionnaire development

We developed the questionnaire items on the importance of the swine industry and potential problems associated with LSSF from the list of problems and benefits that local newspapers had reported. The questionnaire was pre-tested on a small sample of stakeholders and reviewed for accuracy and phraseology by scientists from the University of Illinois College of Agriculture, Consumer and Environmental Sciences. We closely followed Don Dillman's (2000) recommendations for distributing survey instruments, including five total contacts: an initial cover letter prior to mailing the survey instrument, first mailing of instrument, a reminder postcard, second mailing, and a follow-up telephone call. The time period from initial mailing to close was approximately 2 months.

Response rate

We had an extremely high response rate of 72 percent overall from the individuals contacted. Having a high response rate is good, because it indicates that we can be fairly well-assured that

the range of responses is typical of what each group surveyed is actually feeling. We have attributed this high response rate to both the high level of civic responsibility of the respondents and to the importance of the question of swine farm expansion to both farmers and those in nearby communities.

We also surveyed roughly a fourth (26 out of 109) of the people who did not respond to see if there was a systematic negative reaction to the survey instrument.[2] Only two individuals indicated any problem with the content of the questionnaire: one who thought the questionnaire might hurt farmers and another who thought the questionnaire would help.[3] The most common answers were split reasonably evenly into three groups: people who thought they had sent the questionnaire in or said they had filled out portions of it, people who were disqualified for a variety of reasons (such as being too ill to fill out the survey), and people who said they were too busy to fulfill the questionnaire. None of these individuals indicated a problem with the content of the survey, although several quite reasonably pointed out that it was very long.

Findings

Overall – as expected – farmers with LSSF were significantly more likely than other groups to consider the swine industry, particularly LSSF, to be an important part of the Illinois economy. Activists held the opposite view: LSSF are not at all important to the state economy and are harmful to the economic well-being of Illinois's small-scale swine operations. Zoning board officials, journalists, and residents were in between the extremes of farmers and activists, although these three groups tended slightly towards the activist position with respect to the importance of LSSF for Illinois.

Regarding the likelihood of LSSF causing environmental health problems, farmers and activists were again at opposite ends of the spectrum. However, in this case zoning board officials were as likely as farmers not to see any problems, with journalists in close agreement. Residents were notably closer to the activist position on their views of problems stemming from LSSF.

Importance of the swine industry to Illinois economy

Farmers were significantly more likely to agree that LSSF have large overall economic benefits. Eighty-two (82) percent of these farmers agreed or strongly agreed with the statement that "*large-scale swine facilities bring in far more opportunities to the state than problems*" (see Table 1a). All other stakeholder groups were far less positive that large hog farms were an overall good for Illinois. Zoning board officials and newspaper reporters were most likely to be neutral, residents and activists to most likely disagree with the statement.

Farmers were also significantly more likely than any other group to indicate that rural communities would lose income if hog operations went to other states (see Table 1b). Although

2 Systematic negative responses generally indicate a problem with the questions.

3 Specifically, one potential respondent said that he refused to fill out the survey because he "thought it might be a threat to their good neighbor," while the other said that in reality he had "locked horns" with a large scale facility and he "thought the survey was a trick" from the farmer.

the majority of residents, zoning board officials, and journalists all agreed with this statement, residents also believed that LSSF displaced more jobs than they provided (see Table 1c).

The majority of large-scale swine farmers agreed with statements that supported the importance of large-scale swine farms for the Illinois economy (see Table 1d, Table 1e, and over 40% agreement for Table 1f)) but downplayed the negative effects of LSSF facilities for other parts of the Illinois swine industry (see Table 1g –Table 1i). Their nearest neighbors had virtually the exact opposite image of LSSF impact on the state economy. Compared to the farmer group, residents were significantly more likely to believe that LSSF controlled the hog market in Illinois (see Table 1g) and to disagree with the idea that LSSF were the future of the Illinois pork industry (see Table 1d). Neighbors were far more likely to believe that small swine farms cannot compete economically with LSSF (see Table 1h) and far more likely to believe that LSSF have driven farmers into bankruptcy (see Table 1i).

Reported frequency of odor from swine facilities

Farmers and residents strongly disagreed on the frequency of detectable odor emitted from swine facilities (see Table 2). Twenty-seven percent of farmers reported they never detected such odors, whereas only six percent of their neighbors did so. Also, 15 percent of residents reported the odor to be detectable daily, but no farmer agreed with this statement. Activists also had a significantly different perspective of odor than did farmers. But there were essentially no differences between farmers and journalists or zoning board officials.

Stakeholder perceptions of statements of impact of large-scale swine facilities

Farmers and zoning-board members were more likely than not to agree that LSSF are less harmful to the environment and cause less biological damage to the environment, in part because buildings are newer (see Table 3a) and have the latest technology (see Table 3b). There was no significant difference between farmers and zoning-board officials with respect to their view that waste lagoons had not leaked (see Table 3c), but they differed as to whether waste run-off had contaminated nearby streams and rivers (see Table 3d and Table 3e) and polluted drinking water (see Table 3f).

Residents and activists were significantly less likely than farmers to have a positive picture on all questions related to environmental impacts of LSSF. The majority of both residents and activists did not agree that LSSF were less likely to pollute because the buildings were newer (see Table 3a), and more were likely to disagree than to agree with the notion that the newer technology on LSSF would lower the likelihood of a pollution episode (see Table 3b). Residents were significantly less likely than farmers to minimize the environmental effects of LLSF (see Table 3c-3g). So, for example, while over 90 percent of farmers agreed the waste lagoon had not leaked, only 36 percent of residents held the same view (see Table 3c). Along the same lines, although nearly 90 percent of farmers believed that nearby rivers and streams have not been contaminated by waste run-off; only a third of residents thought this was so, with another third indicating they believed that nearby water was being affected (see Table 3d). Residents were significantly more likely than farmers to believe that people have become sick from hog-farm

odors, but a substantial minority still agreed that hog odors had not caused sickness in the area (see Table 3g).

The majority in all stakeholder groups recognized that farmers are facing considerable financial constraints, including that farmers need to grow in size of operation in order to provide for children to stay in farming (see Table 3h) and that likewise farmers need to expand in order to stay competitive (see Table 3i). But the majority of residents, activists, and zoning board officials also see LSSF as lowering property values of nearby human housing (see Table 3j).

Modifying the status quo

Only a few respondents in the entire sample population claimed that people in the community actively want LSSF in their area (see Table 4a). While the majority of farmers believe that now that such operations are established, people have come to accept them (see Table 4b), 48 percent of farmers believe that there is still a lot of resistance to LSSF (see Table 4c). Indeed, the farmers – more than any other group of stakeholders – believed that community reaction could affect the success of LSSF (see Table 4d – 4g).

The majority of activists and a substantial minority of residents believe people have not accepted the swine farms once they have been sited (see Table 4c), and that they would actively fight to get rid of these facilities if there were a chance of seeing them ousted (see Table 4g). At the same time, however, residents, activists, zoning board officials, and journalists also largely agreed that there is very little chance of active resistance being ultimately successful (see Table 4d and 4e).

Controversy and large-scale swine facilities

Slightly fewer than half of farmers (48%) and only 42 percent of residents indicated that the building or expansion of LSSF had been controversial in the local area (see Table 5a). Of those who indicated that it had been, the mean level of controversy reported was relatively moderate, approximately midrange between the two extremes of least conflict and most conflict (Table 5b). Most groups (activists excepted) indicated that overt objections to expanding swine operations lasted for less a year (Table 5c).

Farmers, zoning board officials, and reporters were substantially more satisfied with the outcome of the controversy over building LSSF than were either residents or activists (see Table 5d). Furthermore, there were significant differences between residents or activists and farmers regarding level of perceived support for LSSF (see Table 5e). When it came to personal support or opposition to building LSSF, the majority of large-scale swine farmers supported construction of LSSF. Almost as many residents were neutral as were opposed, but only a few (less than 20 percent) supported expansion, whereas the majority of activists opposed it. Zoning board officials and reporters were largely not involved; only a few zoning board officials and no reporters supported expansion of LSSF (see Table 5f).

Activists were the most involved group among the stakeholders (see Table 5g). Ninety-five percent told their families about their feelings about the LSSF. All of them expressed their

feelings to the people in town, and over 60 percent of them attended hearings and community meetings and told farmers how they felt. Ten percent went so far as to file a lawsuit (see Table 5g).

The residents, while more passive than the anti-LSSF activists, were a great deal more active than what would generally have been expected in terms of public engagement. The activities that required the least active effort were extremely high in terms of involvement, including telling family (80%), town people (62%), and farmers (42%) how they felt. Relatively high numbers of residents also took additional steps, including attending a community meeting (21%) or participating in public protest (10%) (see Table 5g). A much larger percentage of the farmers attended community meetings, hearings, or helped lobby for bills than did the residents (see Table 5g).

Zoning board members and reporters – as intermediate powerbrokers between farmers and oppositional groups – were the two main groups of stakeholders who were targets of actions opposing or supporting building a LSSF. Almost all zoning officials were the subject/target of letters in local newspapers. And both zoning officials and reporters were approached by family members and people in town expressing their opposition to or support of hog farm expansions through a variety of means – conversation, letters, phone calls (see Table 5h).

Perceived influence of newspaper

Every single person (100 percent) of the sampled residents thought that nearby residents as a group had instigated the controversy connected with building or expanding nearby hog operations. This view was held by the majority of activists, zoning board officials, and reporters. Only farmers as a group pinpointed other points as the start of the conflict. Slightly over a third of the farmers said that opposition was started by people who were new to the community or by a group of new and nearby neighbors (38 percent) (see Table 6a). About a third of all farmers, in fact, blamed newspapers for starting the conflict, while residents and activists leaned toward saying that local newspapers smoothed over conflicts (see Table 6b).

Stakeholder demographics

As expected, the respondents were largely conservative (see Table 7a), married (see Table 7b), male (see Table 7c), parents (see Table 7d), between the ages of 40 and 60 (see Table 7e), who had at least a high-school education (see Table 7f), had lived a long time in the community (see Table 7g), had a good deal of personal background (see Table 7h), friends and acquaintances in agriculture (see Table 7i and Table 7j).

There were some differences among the different groups throughout the demographics (see Tables 7a -j). Reporters were less likely to have been raised on a farm and had somewhat fewer acquaintances and friends with farm backgrounds. They also were slightly less likely to be married, and had fewer children, which was consistent with a relatively high proportion of the group being in the below-30 age category. Reporters also were somewhat more likely to have lived in the community fewer years (under 10), consider themselves independent politically, and have graduated from college, all characteristics which are consistent with reporters as a whole.

Activists, as a whole, were relatively more likely to be female, slightly more likely to be new to the community, and more likely to consider themselves independent politically than farmers, residents, or zoning officials. Farmers, zoning board officials, and residents can be reasonably well-described as married men, with over two children, who had lived in the community for a long time and had at least a high-school education. Farmers in particular identified themselves as Republicans. Residents and zoning board officials were more likely to vote for Republicans than candidates in any other party.

Summary

Farmers and residents had significantly different perceptions of the importance of the swine industry to the Illinois economy, of swine farmers' need to grow, and of the potential for LSSF to cause economic or environmental damage, with residents being distinctly less positive than farmers. Nevertheless, a substantive minority, and in some cases a majority, of residents believed the swine industry had a variety of positive economic impacts, and residents largely agreed that farmers need to grow for economic reasons.

Turning more specifically to local controversies over the building or expansion of large hog farms, farmers and residents had essentially identical opinions on the presence, level, and length of controversy, but residents were distinctly less satisfied with and perceived distinctly less support for large-scale operations. In addition, while farmers blamed a range of groups, including newspapers, for starting the opposition to building or expanding existing swine farms, farmers' neighbors uniformly said they (the neighbors) had started the conflict. Residents also were significantly more likely to say that the switch to large-scale farming was a fait accompli, but they were far less satisfied with the presence of the facilities than farmers thought they were. The most dramatic differences between farmers and residents were largely associated with the degree of effect that large-scale swine farms have. Residents reported considerably more days with detectable odors than farmers do, were considerably more likely to believe that there were problems with water pollution harming the environment and drinking water, and distinctly more likely to report loss of value of homes near hog farms.

Hence, the results indicate a reservoir of unhappiness with large-scale hog farms. People living near hog farms saw problems with the facilities and less support for the facilities than did the farmers who run them and a significant minority indicated they would oppose these facilities if given a reasonable chance of succeeding.

References

Albrecht, Don. 1997. "The Changing Structure of U.S. Agriculture: Dualism Out, Industrialism In," *Rural Sociology* 62(4):474-490.

Albrecht, Don. 1998. "The Industrial Transformation of Farm Communities: Implications for Family Structure and Socioeconomic Conditions." *Rural Sociology* 63(1):51-64.

Dillman, Don A. 2000. *Mail and Internet surveys: The tailored design method. New* York: J. Wiley.

Stock, Catherine. 1997. *Rural Radicals: From Bacon's Rebellion to the Oklahoma City Bombing.* Viking Penguin.

Thompson, Michael D. 2000. "This Little Piggy Went to Market: The Commercialization of Hog Production in Eastern North Carolina from William Shay to Wendell Murphy." *Agricultural History* 74(2):569-584.

Section 1. Importance of the swine industry to the Illinois economy.

Stakeholders' perceptions of the importance of the swine industry.

Table 1a. Stakeholders' reaction to the statement: Large-scale swine facilities bring in far more opportunities to the state than problems.

Stakeholders	Percent[4]					(N)	Sig.[5]
	SD*	D	N	A	SA		
Farmers	6	6	6	32	50	34	---
Residents	20	22	32	17	9	170	.000
Activists	43	10	19	24	5	21	.000
Zoning board	11	13	42	24	11	38	.001
Reporters	8	8	54	23	8	13	.007

*SD = Strongly disagree, D = Disagree, N = Neither Agree or Disagree, A = Agree, SA = Strongly Agree.

Table 1b. Stakeholders' reaction to the statement: Rural communities lose income when hog operations go to other states.

Stakeholders	Percent					(N)	Sig.
	SD	D	N	A	SA		
Farmers	---	---	6	15	79	34	---
Residents	10	10	26	35	19	170	.000
Activists	29	19	19	14	19	21	.000
Zoning board	11	3	21	40	26	38	.000
Reporters	---	---	15	61	23	13	.001

[4] Some rows do not add exactly to 100 percent due to rounding errors in reporting.

[5] This column indicates if farmers and other stakeholders have significantly different perceptions on the statement.

Table 1c. Stakeholders' reaction to the statement: Large-scale facilities cost more jobs than they provide.

Stakeholders	Percent					N	Sig.
	SD	D	N	A	SA		
Farmers	44	32	12	12	---	34	---
Residents	6	20	38	23	14	169	.000
Activists	20	25	5	30	20	20	.002
Zoning board	3	37	55	5	5	38	.000
Reporters	---	23	62	8	8	13	.001

Table 1d. Stakeholders' reaction to the statement: Large-scale swine facilities are the future of the Illinois pork industry.

Stakeholders	Percent					N	Sig.
	SD	D	N	A	SA		
Farmers	6	15	15	41	24	34	---
Residents	14	16	31	30	9	172	.016
Activists	35	10	25	25	5	20	.004
Zoning board	3	18	26	47	5	38	NS
Reporters	8	15	31	46	0	13	NS

Table 1e. Stakeholders' reaction to the statement: Illinois needs new farms to keep packing plants from going out of business.

Stakeholders	Percent					N	Sig.
	SD	D	N	A	SA		
Farmers	---	15	35	15	36	34	---
Residents	12	21	36	22	8	171	.000
Activists	30	25	25	15	5	20	.000
Zoning board	5	13	45	29	8	38	.049
Reporters	---	15	39	39	8	13	NS

Table 1f. Stakeholders' reaction to the statement: Without large-scale swine facilities, we will drive the Illinois hog industry out of business.

Stakeholders	Percent					N	Sig.
	SD	D	N	A	SA		
Farmers	6	27	27	21	21	34	---
Residents	19	25	28	23	6	171	.033
Activists	30	30	15	20	5	20	.021
Zoning board	6	22	36	31	6	36	NS
Reporters	8	23	31	39	--	13	NS

Table 1g. Stakeholders' reaction to the statement: Large-scale swine farms control the hog market in Illinois.

Stakeholders	Percent					N	Sig.
	SD	D	N	A	SA		
Farmers	21	29	21	24	6	34	---
Residents	4	10	28	34	24	169	.000
Activists	10	10	5	24	52	21	.000
Zoning board	---	5	46	32	16	37	.000
Reporters	---	15	31	39	15	13	.023

Table 1h. Stakeholders' reaction to the statement: Small swine farms can compete economically with the large-scale facilities.

Stakeholders	Percent					N	Sig.
	SD	D	N	A	SA		
Farmers	12	18	18	36	15	33	---
Residents	29	39	17	11	4	170	.000
Activists	38	14	24	10	14	21	.048
Zoning board	24	45	13	46	3	38	.001
Reporters	8	46	31	8	8	13	NS

Table 1i. Stakeholders' reaction to the statement: Large-scale facilities have driven small farmers into bankruptcy.

Stakeholders	Percent					N	Sig.
	SD	D	N	A	SA		
Farmers	32	29	18	21	---	34	---
Residents	6	15	23	29	27	171	.000
Activists	10	19	10	19	43	21	.000
Zoning board	---	24	40	21	16	38	.000
Reporters	---	---	54	31	15	13	.000

Section 2. Reported problems with large-scale swine facilities.

Table 2. Reports of odor from swine facilities, by stakeholders.

Stakeholders	Percent					N	Sig.
	Daily	Several times a week	Several times a month	Several times a year	Never		
Farmers	0	3	18	53	27	34	---
Residents	15	28	26	25	6	114	.000
Activists	8	31	31	15	15	13	.012
Zoning board	11	11	21	42	16	19	NS
Reporters	0	0	25	50	25	4	NS

Table 3. (series). Stakeholders' perceptions of statements of impact of large-scale swine facilities.

Table 3a. Stakeholders' reaction to the statement: Large-scale swine facilities are less likely to pollute because the buildings are newer.[6]

Stakeholders	Percent					N	Sig.
	False	Probably false	Don't know	Probably true	True		
Farmers	9	24	0	33	33	33	---
Residents	28	24	19	20	9	173	.000
Activists	43	29	5	19	5	21	.000
Zoning board	14	8	28	42	8	36	NS

Table 3b. Stakeholders' reaction to the statement: Large-scale swine facilities are less likely to pollute because they have the latest technology.

Stakeholders	Percent					N	Sig.
	False	Probably false	Don't know	Probably true	True		
Farmers	6	15	9	29	41	34	---
Residents	24	20	19	27	11	173	.001
Activists	38	27	14	5	14	21	.000
Zoning board	8	17	19	44	11	36	NS

6 Not all stakeholder groups were asked each question.

Table 3c. Stakeholders' reaction to the statement: The waste lagoon has not leaked.

Stakeholders	Percent					N	Sig.
	False	Probably false	Don't know	Probably true	True		
Farmers	12	0	3	7	79	33	---
Residents	11	9	44	16	20	166	.000
Activists	33	10	33	14	10	21	.000
Zoning board	0	3	40	14	43	35	NS
Reporters	20	---	---	20	60	5	NS

Table 3d. Stakeholders' reaction to the statement: Waste run-off has contaminated nearby streams and rivers.

Stakeholders	Percent					N	Sig.
	False	Probably false	Don't know	Probably true	True		
Farmers	82	6	0	6	6	34	---
Residents	21	14	33	15	17	171	.000
Activists	5	19	33	24	19	21	.000
Zoning board	21	27	29	9	15	34	.000
Reporters	60	20	0	0	20	5	NS

Table 3e. Stakeholders' reaction to the statement: The waste run-off has caused a fish kill in the rivers and streams.

Stakeholders	Percent					N	Sig.
	False	Probably false	Don't know	Probably true	True		
Farmers	77	12	3	9	0	34	---
Residents	27	13	34	15	11	169	.000
Activists	24	19	29	10	19	21	.000
Zoning board	31	17	31	17	3	35	.000
Reporters	60	20	0	0	20	5	NS

Table 3f. Stakeholders' reaction to the statement: Drinking water has not been contaminated by hog waste.

Stakeholders	Percent					N	Sig.
	False	Probably false	Don't know	Probably true	True		
Farmers	6	3	0	3	88	34	---
Residents	8	11	42	15	24	172	.000
Activists	5	24	33	29	10	21	.000
Zoning board	6	6	37	20	31	35	.000
Reporters	0	0	40	20	40	5	NS

Table 3g. Stakeholders' reaction to the statement: People have not gotten sick from the hog farm odors.

Stakeholders	Percent					N	Sig.
	False	Probably false	Don't know	Probably true	True		
Farmers	12	6	0	6	77	34	---
Residents	16	12	30	22	22	172	.000
Activists	29	24	14	24	10	21	.000
Zoning board	3	17	34	20	26	35	.012
Reporters	0	0	20	40	40	5	NS

Table 3h. Stakeholders' reaction to the statement: Medium-sized farms must grow for children to stay in the business.

Stakeholders	Percent					N	Sig.
	False	Probably false	Don't know	Probably true	True		
Farmers	3	6	3	41	47	34	---
Residents	13	9	15	40	23	173	.001
Activists	25	15	5	45	10	20	.002
Zoning board	6	8	19	31	36	36	NS

Table 3i. Stakeholders' reaction to the statement: Farmers have had to grow to stay competitive.

Stakeholders	Percent					N	Sig.
	False	Probably false	Don't know	Probably true	True		
Farmers	0	6	6	29	59	34	---
Residents	6	7	9	41	37	174	.009
Activists	21	11	11	32	26	19	.008
Zoning board	3	0	16	38	43	37	NS

Table 3j. Stakeholders' reaction to the statement: Homes near hog farms have decreased in property value.

Stakeholders	Percent					N	Sig.
	False	Probably false	Don't know	Probably true	True		
Farmers	56	15	21	9	0	34	---
Residents	12	6	23	23	36	173	.000
Activists	5	0	10	38	48	21	.000
Zoning board	14	8	28	42	8	36	.000
Reporters	40	0	60	0	0	5	NS

Table 3k. Stakeholders' reaction to the statement: Hog farm waste has harmed the beauty of local waterways.

Stakeholders	Percent					N	Sig.
	False	Probably false	Don't know	Probably true	True		
Farmers	94	3	3	0	0	---	---
Residents	24	19	28	16	13	172	.000
Activists	14	19	24	14	29	21	.000
Zoning board	25	33	33	6	3	36	.000
Reporters	40	20	20	0	0	5	NS

Table 3l. Stakeholders' reaction to the statement: Producers with large-scale swine facilities can deliver larger and healthier litters.

Stakeholders	Percent					N	Sig.
	False	Probably false	Don't know	Probably true	True		
Farmers	21	27	3	24	24	33	---
Residents	15	18	33	22	12	172	NS
Activists	43	14	10	24	10	21	NS
Zoning board	14	11	28	36	11	36	NS

Section 4. Current opposition to swine facilities.

Table 4a. Stakeholders' reaction to the statement: Overall people in the community want large-scale swine facilities in this area.

Stakeholders	Percent					N	Sig.
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree		
Farmers	23	34	34	9	0	35	---
Residents	32	37	24	6	1	161	NS
Activists	57	24	19	0	0	21	.007
Zoning board	16	46	35	3	0	37	NS
Reporters	0	62	37	0	0	8	NS

Table 4b. Stakeholders' reaction to the statement: Now that the hog farms are here, most people have accepted them.

Stakeholders	Percent					N	Sig.
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree		
Farmers	6	17	20	49	9	35	---
Residents	16	23	21	37	4	160	.023
Activists	35	25	15	20	5	20	.005
Zoning board	6	14	25	50	6	36	NS
Reporters	0	25	25	50	0	8	NS

Table 4c. Stakeholders' reaction to the statement: There is still a lot of resistance to large-scale swine facilities.

Stakeholders	Percent					N	Sig.
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree		
Farmers	11	20	20	31	17	35	---
Residents	7	13	25	34	22	160	NS
Activists	5	5	24	33	33	21	.059
Zoning board	3	11	24	51	11	37	NS
Reporters	0	12	25	62	0	8	NS

Table 4d. Stakeholders' reaction to the statement: It's a done deal. Nothing that people in the area say will make a lot of difference.

Stakeholders	Percent					N	Sig.
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree		
Farmers	3	31	29	23	9	35	---
Residents	5	10	26	34	25	159	.001
Activists	0	19	10	33	38	21	.004
Zoning board	0	14	24	41	22	37	.003
Reporters	0	0	12	25	63	8	NS

Table 4e. Stakeholders' reaction to the statement: Nothing is going to happen until there is an accident or people get sick.

Stakeholders	Percent					N	Sig.
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree		
Farmers	18	39	15	12	15	33	---
Residents	4	10	18	39	28	160	.000
Activists	11	16	21	16	37	19	.039
Zoning board	3	19	19	42	17	36	.006
Reporters	0	0	12	25	63	8	.030

Table 4f. Stakeholders' reaction to the statement: The small farmers have already been forced out, so the size of hog farm doesn't make a difference.

Stakeholders	Percent					N	Sig.
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree		
Farmers	21	44	18	12	6	34	---
Residents	16	21	22	31	11	158	.007
Activists	25	35	15	15	10	20	NS
Zoning board	5	30	30	22	14	37	.012
Reporters	12	38	25	25	0	8	NS

Table 4g. Stakeholders' reaction to the statement: If there were a chance of getting rid of the swine facilities, people here would be active in fighting them.

Stakeholders	Percent					N	Sig.
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree		
Farmers	11	34	29	20	6	35	---
Residents	4	18	37	27	14	160	.009
Activists	5	5	29	38	24	21	.002
Zoning board	3	14	46	24	14	37	.021
Reporters	0	25	50	12	12	8	NS

Table 4h. Stakeholders' reaction to the statement: The fear of having large-scale swine facilities was a lot worse than what actually happened.

Stakeholders	Percent					N	Sig.
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree		
Farmers	6	9	11	34	40	35	---
Residents	16	18	28	33	6	159	.000
Activists	30	20	25	15	10	20	.001
Zoning board	5	11	27	51	5	37	.390
Reporters	0	0	37	50	12	8	NS

Section 5. Controversy and large-scale swine facilities.

Table 5a. Percent indicating presence of controversy over proposed large-scale swine farm, by stakeholder group.*

Stakeholders	Yes	No	N	Sig.
Farmers	48	52	29	---
Residents	42	58	174	NS
Activists	71	29	21	NS
Zoning board	54	46	37	NS
Reporters	60	40	6	NS

- The question asked was: "Was there any controversy over the construction or expansion of this operation?"

Table 5b. Mean level of perceived controversy over building a large-scale swine facilities, by stakeholder group.*

Stakeholders	Mean	N	Sig.
Farmers	4.3	13	---
Residents	4.1	85	NS
Activists	6.0	13	NS
Zoning board	5.3	21	NS
Reporters	4.6	5	NS

- The question asked was: "On a scale from 1 (a couple of people spoke to the farmer) to 10 (the farmer received death threats), please indicate how much controversy surrounded the operation." People who answer "no" to the presence of controversy did not answer this question.

Table 5c. Mean level of perceived length of controversy on large-scale swine facilities, by stakeholder group.*

Stakeholders	Mean	N	Sig.
Farmers	3.9	13	---
Residents	3.4	83	NS
Activists	4.3	15	NS
Zoning board	3.7	7	NS
Reporters	3.7	20	NS

- The question asked was: "How long did the controversy last? (1) = less than one week; (2) = 1 week to 1 month; (3) = 1 month up to 6 months; (4) = 6 months to a year; (5) = 1 year up to 2 years; (6) 2 years or greater."

Table 5d. Percent indicating satisfaction with resolution of large-scale swine facility controversy, by stakeholder group.

Stakeholder	Percent satisfied	N	Sig.
Farmers	70	13	---
Residents	43	89	.08
Activists	29	14	.04
Zoning board	65	17	NS
Reporters	100	3	NS

Table 5e. Mean level of perceived support for large-scale swine facilities, by stakeholder group.*

Stakeholders	Mean	N	Sig.
Farmers	5.2	35	---
Residents	4.1	166	.02
Activists	3.9	20	.05
Zoning board	4.4	37	NS
Reporters	4.0	6	NS

- The question asked was: "How do people in area feel about LSSF." The scale ranged from 1 to 10 with 1 being extremely opposed to the large-scale swine facilities to 10 being extremely supportive.

Table 5f. Stakeholders' direction of support for the building of large-scale swine facilities:

Stakeholders	Support	Not involved	Opposed	N
Farmers	77	23	0	35
Residents	17	40	43	138
Activists	21	16	63	19
Zoning board	13	73	13	30
Reporters	0	67	33	6

- The question asked was: "Many people have been involved in various sorts of actions to either support or oppose the construction of large-scale swine facilities. Please circle the number that best reflects your actions." The choices were: (1) involved in supporting, (2) involved in opposing, (3) not involved at all.

Table 5g. Stakeholders' reports of actions they took opposing or supporting building a large-scale swine operation, percent indicating they took action.

Actions	Farmers	Zoning Board	Reporters	Residents	Activists
	Percent taking action (N)	Percent action (N)	Percent action (N)	Percent action (N)	Percent action (N)
Told my family my feelings	NA*	52 (25)	38 (8)	80 (138)	95 (20)
Told people in town how I feel	NA	25 (8)	53 (8)	62 (138)	100 (20)
Attended a community meeting	67 (30)	53 (30)	38 (8)	21 (138)	90 (20)
Wrote a letter to (opinion piece for) the local newspaper	20 (30)	97 (30)	0 (8)	5 (138)	45 (20)
Told the farmer how I felt	NA	33 (30)	25 (8)	42 (138)	63 (19)
Wrote a letter to the farmer	NA	NA	NA	8 (138)	20 (20)
Attended hearings	47 (30)	30 (30)	50 (8)	2 (138)	65 (20)
Participated in public protest	0 (30)	3 (30)	0 (8)	10 (137)	50 (20)
Helped to lobby for a bill in Springfield	40 (30)	7 (30)	0 (8)	3 (138)	50 (20)
Testified at state hearing	10 (30)	0 (30)	3 (8)	1 (138)	25 (20)
Filed a lawsuit	NA	NA	NA	1 (138)	10 (20)
Gave away free pork	50 (30)	NA	NA	NA	NA

- N represents the total number of respondents for that action.

* Not all questions were asked of every respondent, particularly when we felt that asking the question was somewhat insulting (such as asking the farmer if he wrote a letter to himself). NA represents the category "not asked."

Table 5h. Stakeholders' reports of being the targets of actions opposing or supporting building a large-scale swine operation, percent indicating they took action.

Actions	Farmers	Zoning Board	Reporters
	Percent receiving action (N)	Percent action (N)	Percent action (N)
Family members told me they opposed the hog farm expansion	NA	76 (30)	25 (8)
Family members told me they supported the hog farm expansion	NA	17 (30)	0 (8)
People in town talked to me.	61(31)	NA	NA
People in town told me they opposed the hog facility.	NA	67 (30)	50 (8)
People in town told me they supported the hog facility.	NA	33 (30)	38 (8)
Received phone calls that opposed the large hog operation.	NA	43 (30)	50 (8)
Received phone calls that supported the large hog operation.	NA	20 (30)	75 (8)
Received letters/e-mail/fax that opposed large hog operations.	29 (31)	23 (30)	50 (8)
Received letters/e-mail/fax that supported large hog operations.	NA	23 (30)	50 (8)
Was subject/target of letter in local newspaper.	39 (31)	97 (30)	NA
There was a protest at my operation.	3 (31)	NA	NA
There has a lawsuit filed against my operation.	0 (31)	NA	NA
My swine operation was vandalized.	3 (31)	NA	NA
I have been physically harassed by protesters.	3 (31)	NA	NA
I received death threats.	0 (31)	NA	NA

- N represents the total number of respondents for that action.

Section 6. Newspapers' role in the local controversy over swine farm sitings.

Table 6a. Perceived instigator of the controversy, by stakeholder group.*

Stakeholders	Nearby	New	Near & new	News-paper	Outsider	Other	N	Sig.
Farmers	23	15	23	31	8	0	13	---
Residents	100	0	0	0	0	0	74	.03
Activists	58	0	11	11	11	11	15	NS
Zoning board	74	0	14	1	0	11	19	NS
Reporters	67	0	0	7	7	20	6	.00

- **The question asked was: "If [there was any controversy over the construction or expansion of this swine operation], who started the controversy?"**

Table 6b. Mean for perceived influence of newspaper, by stakeholder group.*

Stakeholders	Mean	N	Sig.
Farmers	5.8	12	---
Residents	3.8	77	.03
Activists	3.9	13	.06
Zoning board	4.6	21	NS
Reporters	4.7	7	NS

- **The question asked was: "On a scale from 1 (completely dissolved conflict) to 10 (completely created conflict), please indicate the role of your local newspaper in this controversy."**

Section 7. Stakeholder Demographics.

Table 7a. Stakeholders' political affiliation, by stakeholder group, in percents.

	Republican	Democrat	Independent	Christian Coalition	N
Farmers	78	16	6	0	32
Residents	48	32	17	3	157
Activists	42	11	47	0	19
Zoning board	58	39	3	0	33
Reporters	27	18	55	0	11

Table 7b. Marital status distribution of stakeholder groups, in percents.

	Married	Single	N
Farmers	97	3	35
Residents	85	15	168
Activists	85	15	20
Zoning board	87	14	37
Reporters	69	31	13

Table 7c. Sex distribution of stakeholder groups.

	Female	Male	N
Farmers	0	100	35
Residents	20	80	172
Activists	63	37	19
Zoning board	16	84	37
Reporters	31	69	13

Table 7d. Mean number of children of stakeholder groups.

	Mean	N
Farmers	3.0	35
Residents	2.6	179
Activists	2.4	21
Zoning board	2.6	38
Reporters	1.7	13

Table 7e. Age distribution by respondent groups, by frequency in age group.

	0-30	31-40	41-50	51-60	61-70	71+	(N)
Farmers	1	6	15	10	2	1	35
Residents	19	25	43	36	28	19	170
Activists	0	7	6	4	1	0	18
Zoning Board	1	4	6	12	12	2	37
Reporters	3	0	4	5	1	0	13

Table 7f. Educational levels, in percents.

	Less than High School	High School Graduate	Two year degree	College degree	Graduate Degree	N
Farmers	0	37	26	29	9	35
Residents	6	51	16	19	8	172
Activists	5	33	20	35	5	19
Zoning board	3	43	16	22	16	37
Reporters	0	0	8	62	31	13

Table 7g. Stakeholders' years in community, in percents.

	0	1-10	11-20	21-30	31-40	41-50	51-60	60+	N
Farmers	0	3	6	14	20	34	20	3	35
Residents	5	15	10	16	11	16	12	15	178
Activists	14	5	5	10	15	35	19	0	21
Zoning Board	3	3	8	13	13	13	21	26	38
Reporters	0	23	8	23	23	23	0	0	13

Stakeholder groups' agricultural ties.

Table 7h. Stakeholders indicating past experience with agriculture, percent having experience.*

	Raised on farm	Part-time work on farm	Full-time work on farm	Visited farm relatives	Agricultural degree	N
Residents	72	27	36	22	13	179
Activists	62	20	60	40	10	20
Zoning board	51	22	27	24	14	37
Reporters	33	25	17	17	17	13

* Farmers were not asked their agricultural background.

Table 7i. Stakeholders indicating percentage of acquaintances and friends who are farmers.

	0	Up to 25 percent	26-50	51-75	Over 75 percent	N
Residents	10	21	31	21	17	177
Activists	10	19	43	14	14	20
Zoning board	8	29	50	8	5	38
Reporters	8	69	23	0	0	13

Table 7j. Stakeholders indicating percentage of acquaintances and friends who are pork producers.

	0	Up to 25 percent	26-50	51-75	Over 75 percent	N
Residents	22	70	7	1	0	176
Activists	33	62	5	0	0	20
Zoning board	24	73	3	0	0	37
Reporters	46	54	0	0	0	13

Bridging the Gap Between Legal and Community Standards: Strategies for Successful Siting

Peter Goldsmith[1]

INTRODUCTION

Historically animal agriculture has been a significant social, economic and environmental force for rural America. Animal production creates thousands of jobs and adds value to grain and forages. In some regions animal agriculture is a leading value-adding industry and serves as an important economic engine for a community. Increasingly though there is a growing public awareness of the environmental impacts and nuisances caused by livestock facilities.

The agri-food supply chain values formalization, industrialization, and scale even as the environmental constraints abound. The set of attributes that a multinational retailer (Walmart (US), Carrefour(French), Metro(German), Ahold(Dutch)) requires from its meat supply chain are numerous. Significant in this list of attributes are scale, case ready, shelf-life, uniformity, multiple categories, enhancement, and price to name a few (Goldsmith et al, 2002). To provide these requires large investments in production systems and coordination of the supply chain through packing. Large scale livestock units (CAFOs- confined animal feeding operations), whether they are dairy, feedlot or swine, have become an integral part of modern retails supply chain. While world-wide CAFOs are increasingly relevant to the supply chain and attract capital, they are especially challenged in the US by their community and environmental impact.

A fundamental question exists, can livestock stock systems in the US serve both their communities and their supply chains at the same time. Or are both objectives mutually exclusive? The following report describes research and early findings on this issue of balancing the expectations of the community and the needs of customers.

Background

To date relatively little work has been done on the environmental economics of confined animal feeding operations. For example in Illinois, where the Livestock Facilities Management Act was initiated to help livestock producers find relief, net positive investment flows to livestock have not occurred. The reasons for a lack of investment response are numerous. One significant reason relates to the risk associated with siting a CAFO in the state. These would not be so much the risks that an environmental mishap might occur, but the risk that at a future date the community in part or in its entirety might deem the facility offensive and initiate legal proceedings seeking closure. The LMFA, as well as other tactics, has failed to completely address those risks. While the intent was admirable, to regulate and bring rigor to the siting process, the developers of the Act failed to account for the underlying economics related to discommodity production; mostly, but not limited to odor and water issues.

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For example, think of odor as an economic good. In our case it is an economic bad because it has a negative price. People need to be "paid" to consume (smell) it. Flowers produce odors that are an economic good; a fragrance. Livestock odor is only an economic "bad" when it leaves someone's farm and is smelled by a neighbor. The hog farm as a business produces both meat and odor, one is a good and one is a bad. Every firm produces both goods and bads. The reason society allows bads to be produced is that the goods outweigh the bads. In the marketplace one has a positive price and one a negative price. One aspect of bads that is challenging is that sometimes bads become a public issue. A consumer can choose to not consume pork; the same may not be true for odor. Historically, farms were smaller, population was less dense, the rural population was more homogeneous, and livestock production more common. Odor in turn was a much more benign "bad" and generally a private "bad."

Much has changed in the US in terms of our attitudes towards livestock production systems. Illinois for example, requires since 1991, that new livestock facilities locate at least ¼ mile from a non-farm residence and ½ mile from a populated area. These setback requirements were derived based upon the typical types and sizes of livestock facilities operating in Illinois in late 1980s (IEPA, 1996). The setback provisions were intended to greatly reduce the potential for the occurrence of livestock odor problems.

After the adoption of the current setback requirements, some concerns were raised that the setback provisions were inadequate for large-scale operations. To address this concern, the Illinois Environmental Protection Agency (IEPA) investigated the potential impact of increasing the setback provisions. Using eleven representative townships as examples, they used detailed maps and current setback regulations to exactly specify the extent of potential effected parties from specific swine facilities. The Agency found that between 40% and 60% of the land area in each township would need to be included within a comprehensive setback if all rural residences were assumed to be non-farm residences (IEPA 1996). Meaning that, densities were such that there was really no safe haven, even under current regulations. If in fact there was competition over rural amenities, the current law was inadequate and extending the setbacks was unrealistic.

The Problem

Though industrialized agriculture is a modern phenomenon, the problem it creates is the classic problem in economics of the conflict over property rights. Rural amenities such as clean air and clean water are rural amenities. Historically rural population densities were low so competition for these amenities was limited. With changing demographics, technologies, and infrastructure, rural areas are populated more and more by an urban populace. With greater heterogeneity and density in the population, conflicts over resource use are bound to arise. Now add to the situation the industrialization of animal agriculture. Because of their scale, modern livestock facilities place greater demands on the rural resources such as air and water, intensifying the competition for rural amenities even more.

The challenge for policy makers is how to reconcile the differences over how public bads such as odor, water usage, water pollution, sight pollution, light pollution, and traffic, are distributed between CAFOs and their neighborhoods. The problem is not new because policy makers have

dealt with industrial facilities and their environmental and community impact for over thirty years. The context in the case of livestock production is new.

Research Questions

- Is there a harmed party from livestock production?
- If so, should they be compensated for their losses?
- And if so, how much should they be compensated?
- How do the benefits from production compare to the costs from production?
- Knowing the benefits and costs, might there be room to compromise?
- What is the role of government?
- How do you bridge the gap between the legal standards and the community's expectations?

Research Approach

The theme of this research program is that for the livestock industry to grow it needs to attract capital. For net positive flows of capital to occur the business environment both in terms of risk and return need to be improved relative to alternative uses of agro-industrial capital. The siting problem contributes to both; raising the cost of production by not siting efficient units and raising risk by attracting community ill-will and the threat of legal action. The Livestock Management Facilities Act (LMFA), while a positive step, has not corrected the problem enabling positive flows of capital to resume. There still appears to be a gap between what the community expects and what the law specifies.

To begin to understand these issues and answer the above research questions, four integrated research projects have been engaged. The objectives of the four studies are three fold: 1) to understand the concept of industrial legitimacy and how businesses effectively thrive in sync with their communities; 2) to understand if the US/Illinois livestock industry can reverse recent trends and begin to attract capital in light of the siting problem and the opportunities for livestock investment abroad?; 3) If it is possible, what ere the essential elements and what might an appropriate business environment look like? Part of the work looks at how livestock and meat are produced in the country and the dynamics of the global meat complex. Other components assess the benefits and costs of large scale livestock production. The final element focuses on solutions; management and policy changes that might create a more sustainable business model.

Below are four brief overviews of research projects designed to address the objectives. The first is complete. The second is near completion, 1st quarter 2004. The third project has been underway for six months and will be completed during the summer of 2004, and the final project has just begun and is not due for completion until the second quarter of 2005.

Research Projects (1-4)

1) Understanding the Economic Benefits of Livestock Production

This research analyzed the economic impact of livestock on the State's economy at the county, regional, and state level. Tax, labor, and multiplier values were generated and inter

and intra industry comparisons were made. The study resulted in two reports (Goldsmith and Hedris, 2001; Goldsmith and Kim, 2002):

> *The Economic Impact of Illinois Livestock Industry*
> http://www.ace.uiuc.edu/faculty/goldsmith/il_livestock.pdf
>
> *The Economic Impact of Illinois Livestock Industry: Supply Chain Linkages*
> http://www.ace.uiuc.edu/faculty/goldsmith/livestock8_02.pdf

2) Understanding the Economic Costs of Livestock Production

While the benefits were now understood from the first studies, the costs were not. For efficient markets to emerge and capital to flow properly, it is very important that the benefits and costs both be well understood. Economist's call this "getting the prices right." Measuring the negative impact from CAFOs is very difficult to measure. While neighborhood complaints may be valid, they are very difficult to quantify. Harm may be inflated, just has net benefits estimations may be inflated by CAFO operators. Engineers have struggled to measure both the production and the impact of odor on neighboring communities, but have been stymied.

We began a study in 2002 to use the best economic techniques to measure the impact of CAFOs on their communities by analyzing the effects of livestock farms on rural residential housing values. Completion is expected in the 1st quarter of early 2004. The study comprises the doctoral dissertation of Mr. Jungik Kim and is entitled:

> *An Assessment of the discommodity effects of swine production on rural property values: A spatial analysis*

Executive Summary

The study focuses on Craven County, North Carolina[2] where there are 26 hog farms ranging from 500 to 13,000 animal units (Figure 1). The essence of the analysis is: does the distance a house is locate from a farm affect its value. Our preliminary estimates show an approximately 5% reduction of the assessed value for 1,000 hogs at ½ mile. The impact declines with distance showing no impact beyond 1.5 miles.

The implications of the study are two-fold. First at the simplest level we have been able to scientifically show that property owners are correct that there can be negative impact to their property values. More importantly, though both property owners and producers can now know the cost. Following the economic logic above, they now can know the prices (negative) of CAFO production. They also can know that if sited properly the benefits of a CAFO can significantly outweigh the costs.

Using our unique methodology we can now assess counties/regions individually. This is important because it is reasonable to believe that the valuation of CAFOs will vary from one

[2] Craven County was chosen because it is a mixed use county in the swine growing region of eastern North Carolina. The county maintains excellent real estate and hog operation data that is suitable for spatial analysis.

community to the next. Having analyzed a particular county the cost can be estimated on a house by house because our unit of analysis is at the house and farm level. This would allow policymakers to differentiate among homeowners. At a practical level that would allow policymakers to provide differential property tax relief to compensate owners for the lower valuations (if existing) from the siting of a CAFO. In such a scenario the county would be able to enjoy the benefits of the CAFO while at the same time compensating harmed parties. Finally, the methodology would allow planners the ability to analyze optimal sites not only within a county but state-wide by factoring in human population density, hog population density (existing and proposed), distances, wind, and current property values. At a practical level planners would then be able to rank sites by their estimated net benefits.

For example, Farm 1 is a medium sized facility with 853 animal units with four houses within a half mile and 16 homes within a one mile radius (Figure 3). Farm 2 is over 3.5 times larger and has twice as many homes within a half mile and a mile. The two farms have significantly different benefit levels in terms of economic impact. They also may have significantly different levels of "cost" in terms of environmental or nuisance impact. By analyzing the specifics of each case and solving for the benefit:cost ratio, a measure of economic sustainability can be derived.

Farms 3 and 4 are located to the southwest of the county seat New Bern. These are larger facilities and are located in very different communities from Farms 1 and 2. While Farm 3 has only three homes within a half mile and 16 within a mile, very close by are a significant number of homes. Many are part of subdivisions, and by Census determination, are located in urban Census tracts. Farm 4, though the smaller of the two, is very close to a significant number of tract homes. According to regional wind records both farms are downwind a most days from their neighbors located to the Northeast.

Each one of the four farms upon complete analysis will have very different benefit:cost ratios. A ranking of preferred locations could be done and decision rules can be set up to compare the various alternatives (see Goldsmith et al, 2003.) As discussed above regional planners and economic development officials can achieve a better understanding of the net impact of large livestock facilities and can act accordingly. Each case has unique features so policy needs to accommodate the differential impact, both positive and negative[3].

3) Meeting Community Standards to Improve Siting of Livestock Facilities

This study was begun in 2003 and was designed to document the gap between the legal and community standards. The assessment is done by conducting detailed text analysis of the LMFA hearing transcripts. The underlying theory behind the research is the notion of industrial legitimacy. For an industry to attract capital and grow, it needs to be a legitimate entity in society. That does not mean it produces no harm but that the benefits outweigh the harm (and the level of real harm is below an absolute threshold). In the case of the Illinois livestock

[3] This kind of analysis can be done Illinois provided spatial real estate data is available.

industry, the LMFA as a legitimizing policy is not sufficient to achieve net capital flows. For example it is not uncommon for producers to choose not to expand or not to site in order to avoid the LMFA hearing process. Many choose to build on smaller scale simply to be exempt for the LFMA process.

The research asks, given there is a gap between the community and legal standards, what can be done about it. One interesting solution the research is exploring may reside in the economic development literature and policies that lead to sustainable business environments. In such cases zoning, tax policy, infrastructure, and regulation has been used to balance the interests of the industry and the community.

The study is due for completion during the summer of 2004. It comprises the Masters thesis of Mr. Filipe Pereira.

Executive Summary

There have been 24 sitings applications between August 1999 and April 2002 that required a hearing: greater than 1000 animal units or construction of an earthen lagoon (Table 1). The average number of animal units was 2,653 (~8,800 feeder pigs), the minimum was 240 (800) and the maximum was 6,120 (20,400). 21 were for swine units and 3 for dairy. There were no feedlot applications. Of the 24, 13 had hearings scheduled. Four were constructed without a hearing because the county did not request one. Ten facilities were constructed. Five applications were withdrawn. Four of the systems were lagoons, one a pit/SlurryStore and the rest deep pits. Six applications were for expansion and the rest for new locations.

The research has begun analyzing the text of the available hearing transcripts using a text analysis software tool. Thinking of the words of the transcripts as data, we will be able to categorize and analyze; terms, requests, complaints, tone, etc by each of the speakers; community spokes-persons, farmer presentation team members, and government officials. Each person and their location are identified before making each comment. One of the objectives is to strip away rhetoric to identify tangible elements that underlie the various positions represented. For example, one might imagine that participants from outside the region may bring different ideas, tone, and knowledge to the hearing than a more local person. Several of the questions to be answered are: does being in a livestock county hurt or help the process? Is there a relationship between population density, hog density, and the quantity and quality of the public comment? How might a better process differentiate between substantive concern and baseless concern?

4) Manure Management Practices by CAFOs in Illinois: How Effective and the Reasons Why.

The fourth project looks at manure management practices by the largest producers of livestock in the state. One of the best ways for an industry to signal its commitment to being a good steward is for not only best management practices be in place, but the variability across the industry be minimal. This can be accomplished through a commitment to self-monitoring and self-policing. A research team from both the Departments of Agricultural Engineering and Agricultural and

Consumer Economics will visit producers in the next year to better understand how manure management is taking place and provide tools, analysis, and resources to those looking to improve. The research also seeks to answer a fundamental question about why if good technology and best management practices are available, there can be such variability in manure management practices?

This project is just underway. The economics' graduate student has yet to be determined.

CONCLUSION

Understanding the adaptation of the livestock industry is difficult. It involves both structural changes in the global meat system, especially as relates to procurement and retailing, and fundamental changes about the use of rural amenities. So for livestock producers both markets and the community standards are changing simultaneously. Often these changes are opposed in expectation.

If the industry is to adapt and grow the answers may lie in better understanding how other industries have adapted in similar situations. Creating a favorable business environment seems critical to both lowering the risk premium associated with livestock capital as well as providing commensurate returns on similar investment found in other locales. It is hoped that this research will provide new insights and practical solutions to challenges facing post-modern livestock production.

REFERENCES

Goldsmith, Peter D. and H. Idris. "The Economic Impact of Illinois's Livestock Industry." Special Report # 94. http://www.ace.uiuc.edu/faculty/goldsmith/il_livestock.pdf College of Agricultural, Consumer, and Environmental Sciences, The University of Illinois. November, 2001. (Also shown in Reports section H above). 70 pages.

Goldsmith, Peter D. and J. Kim. "The Economic Impact of Illinois's Livestock Industry: Supply Chain Linkages." Special Report # 95. http://www.ace.uiuc.edu/Faculty/goldsmith/livestock8_02.pdf College of Agricultural, Consumer, and Environmental Sciences. The University of Illinois. July, 2002. 45 pages.

Goldsmith, Peter D., A. Salvador, D. Knipe, and E. Kendall. "Structural Change or Logical Incrementalism? Turbulence in the Global Meat System." *Journal of Chain and Network Science.* Volume 2 Number 2. 2002: 101-115.

Goldsmith, Peter D., C. Pomar, Z. Tao, and J. Rivest. "Social Welfare and the Selection of the Optimum Hog Slaughter Weight." *The Canadian Journal of Agricultural Economics.* Forthcoming November, 2003

Illinois Environmental Protection Agency. 1996. Summary Report: A study to investigate the potential impact of modifying the new facility setback requirements in the Illinois livestock waste regulations. Office of Environmental Policy. Springfield, Illinois.

Table 1. LMFA Siting Hearing Overview

Illinois Department of Agriculture - Livestock M 04/22/02
Facilities Subject to Public Informational Meeting Requirement

	Date Received	County	Species	Animal Unit	Manure Storage	Construction Site	Status	Meeting Date	Board Decision	IDA Decision	Comments
1	8/2/1999	Effingham	Dairy	240	Lagoon	Existing	Closed	8/30/1999	Yes	Yes	File closed Facility decided to build a concrete strucuture
2	8/20/1999	Hancock	Swine	1218	Deep Pit	New	Closed	10/6/1999	Neutral	Yes	File closed. noitc expired. No construction
3	8/20/1999	Richland	Swine	940	Lagoon	Existing	Closed	10/4/1999	No	N/A	File closed. design never completed, facility out of business
4	9/3/1999	Morgan	Swine	978	Lagoon	Existing	ACK	none requested	N/A	N/A	Has not commenced construction
5	11/9/1999	Christian	Dairy	5040	Lagoon/NL	New	Closed	12/1/1999	No	AIR	File closed Facility withdrew application before complete
6	4/4/2000	DeKalb	Swine	1312	Deep Pit	New	Closed	none requested	N/A	N/A	File closed Facility withdrew application before complete
7	4/17/2000	Macoupin	Swine	1800	Deep Pit	Existing	Con	5/31/2000	Yes	Yes	Facility constructed and in operation
8	8/4/2000	Schuyler	Swine	2781	Deep Pit	New	Con	9/12/2000	No	Yes	Facility constructed and in operation
9	8/2/2000	Kane	Swine	1942	Deep Pit	Existing	AIR	never sent	N/A	N/A	Noitc is AIR. won't be sent to county until complete
10	10/17/2000	McLean	Dairy	6102	Lagoon/NL	New	Ucon	11/28/2000	Yes	Yes	Facility under construction
11	11/28/2000	Christian	Swine	2240	Deep Pit	Existing	Con	none requested	N/A	N/A	Facility constructed and in operation
12	12/18/2000	Hancock	Swine	1951	Deep Pit	New	Con	none requested	N/A	N/A	Facility constructed and in operation
13	3/8/2001	Clinton	Swine	2280	Deep Pit	New	UCon	none requested	N/A	N/A	Facility under construction
14	3/26/2001	DeKalb	Swine	3200	Deep Pit	New	AIR	closed	N/A	N/A	Application closed
15	4/5/2001	Lawrence	Swine	2800	Deep Pit	New	Ucon	none requested	N/A	N/A	Facility under construction
16	4/23/2001	Pike	Swine	3893	Lagoon/NL	New	AIR	7/19/2001	No	AIR	IDA 2nd final determination AIR letter issued. No response
17	7/9/2001	Ogle	Swine	1600	Deep Pit	New	Con	9/10/2001	Yes	Yes	Facility constructed and in operation
18	7/16/2001	Ogle	Swine	1600	Deep Pit	New	Con	9/10/2001	Yes	Yes	Facility constructed and in operation
19	8/1/2001	Woodford	Swine	4800	Deep Pit	New	Closed	10/10/2001	Yes	N/A	Application was withdrawn by facility
20	10/18/2001	Wayne	Swine	2880	Deep Pit	New	Closed	1/3/2002	No		Application was withdrawn by facility
21	11/28/2001	DeKalb	Swine	3200	Deep Pit	New	Closed				Application was withdrawn by facility Changing waste handling system
22	12/21/2001	Woodford	Swine	4800	Deep Pit	New	Con	2/4/2002	Yes	Yes	Facility is under construction
23	3/28/2002	Wayne	Swine	2880	Deep Pit	New	Review1				
24	4/12/2002	DeKalb	Swine	3200	Pit/SlurryStore	New	Review1				County has been petitioned. will be asking for a meeting

Figure 1. Craven County, North Carolina. East-central part of the state. Red dots represent hog farms.

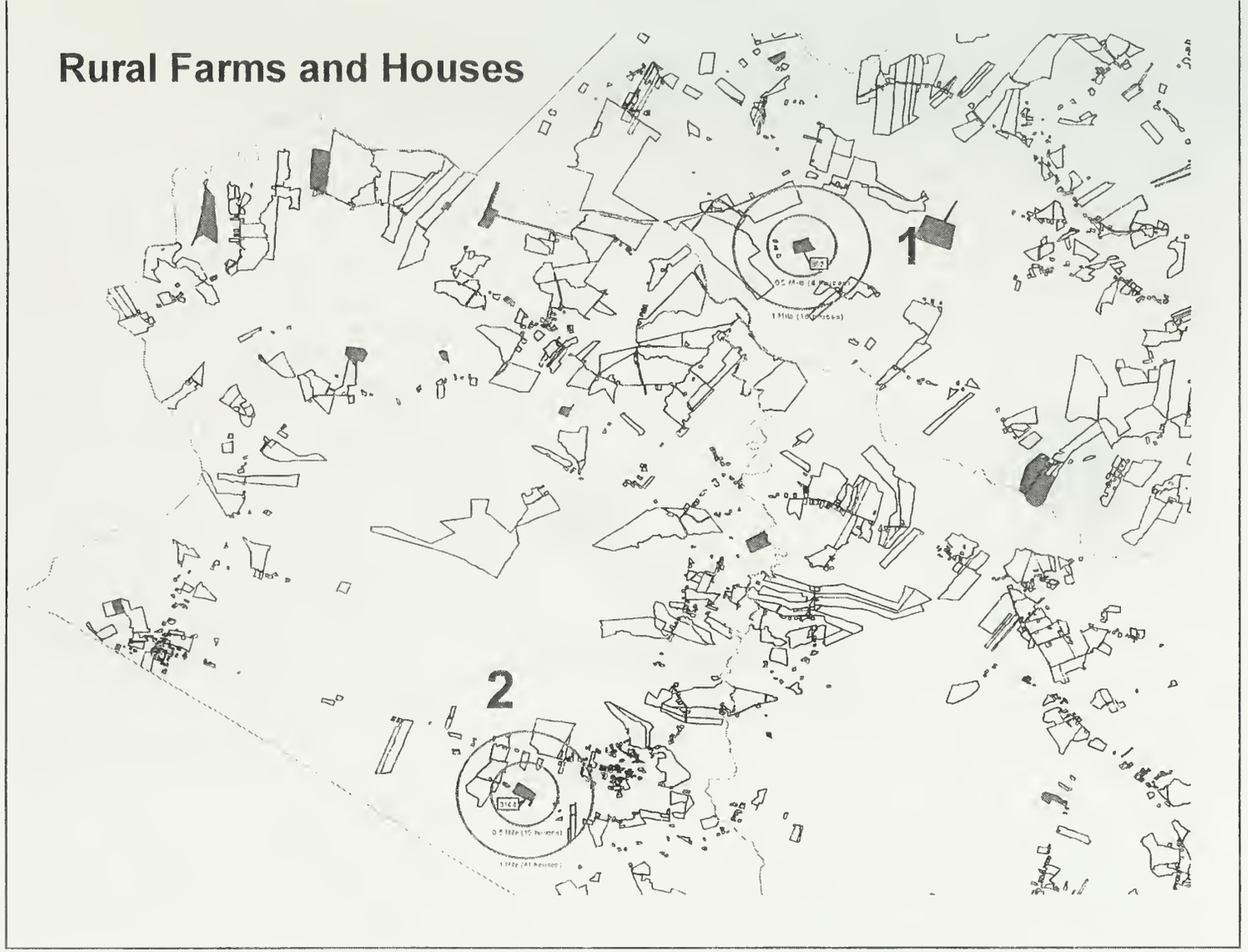

Figure 2. North West Craven County. Red parcels represent hog farms. All other parcels represent residential houses.

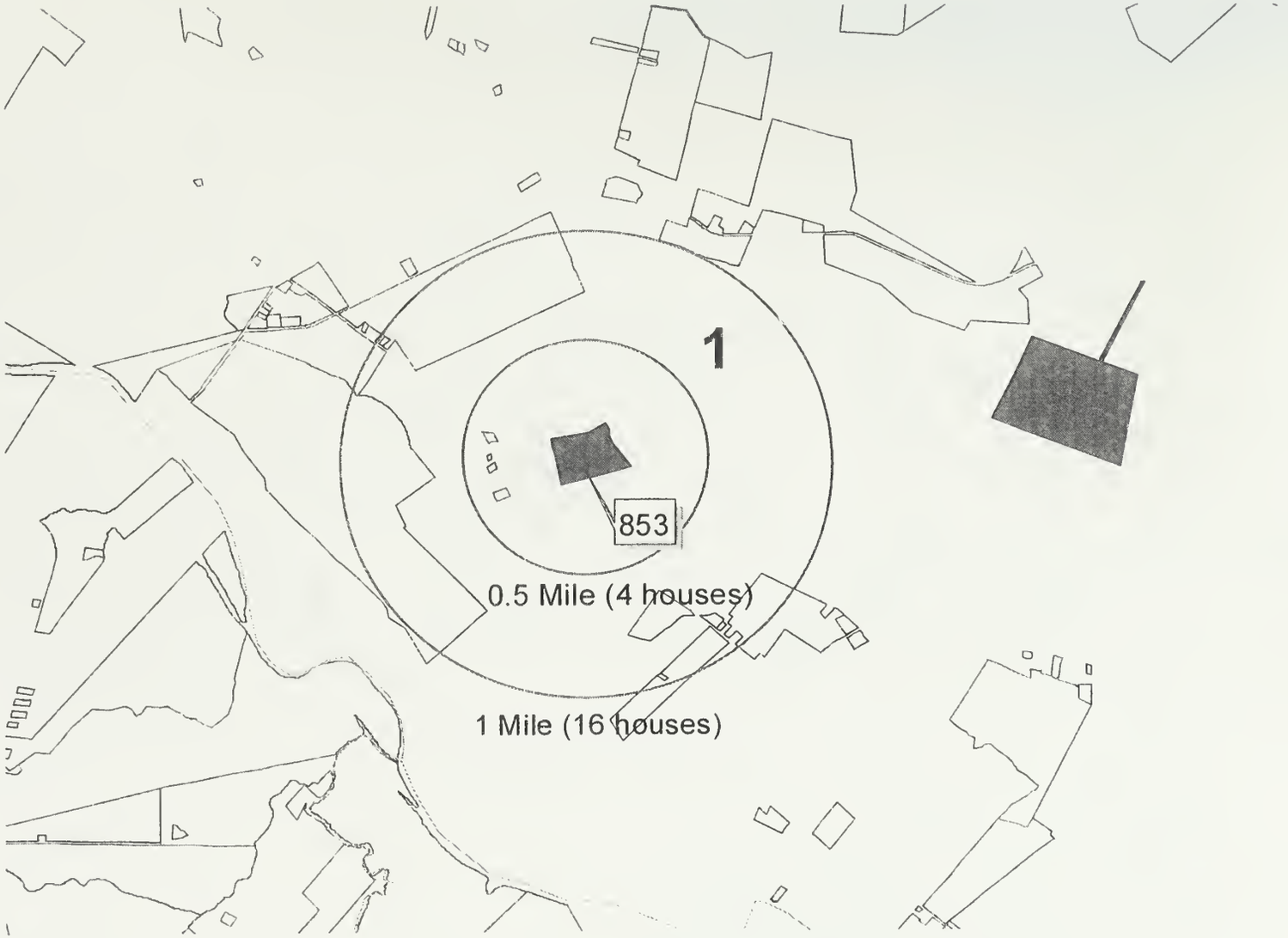

Figure 3. Farm 1 in Detail

Figure 4. Farm 2 in detail

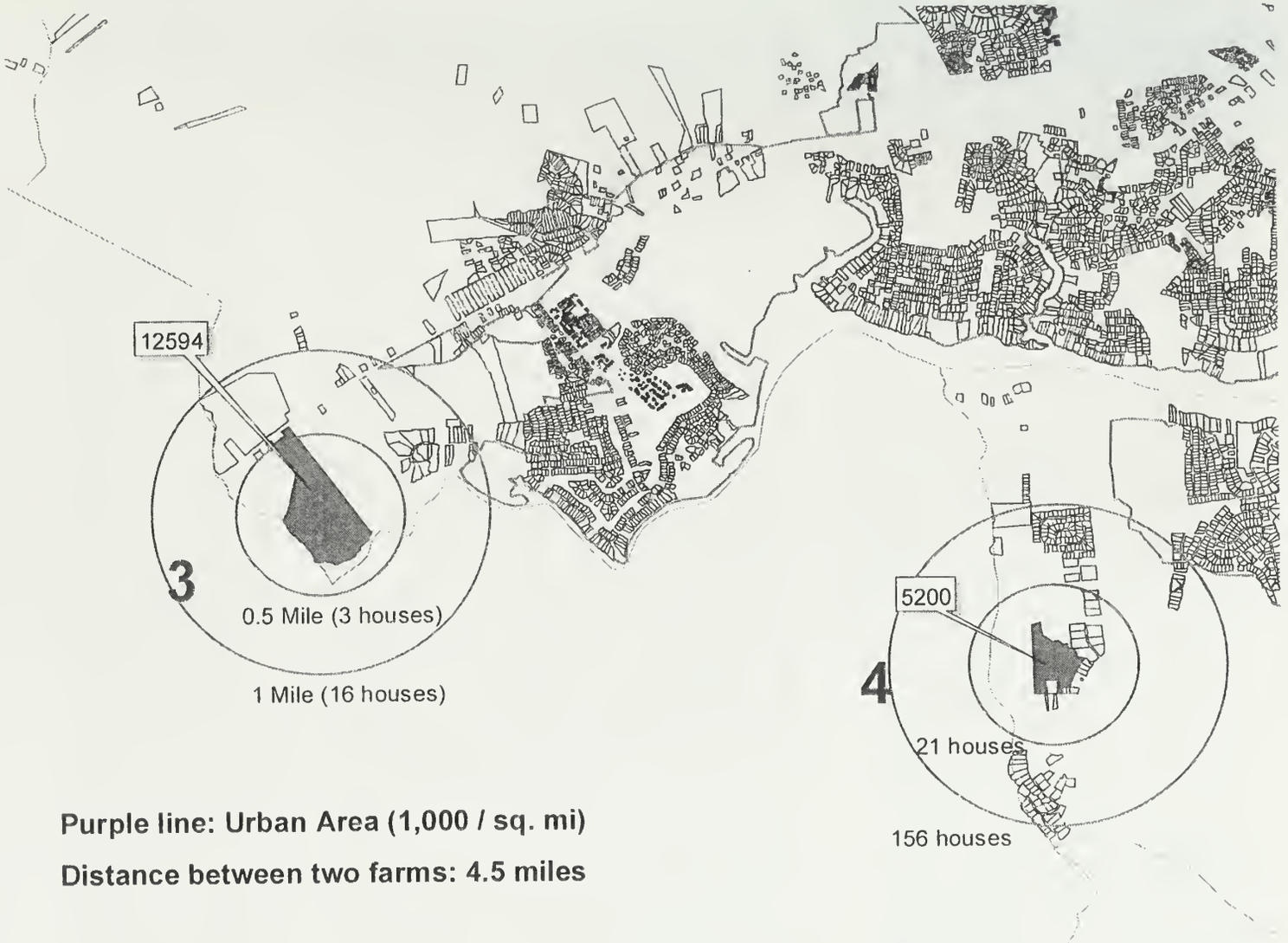

Figure 5. Farms 3 and 4 near New Bern the county seat of Craven County

Overview of Odor Measurement Techniques

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INTRODUCTION

"Odor" is elicited by chemicals in a gas phase which are detected via olfaction producing recognizable smells (cinnamon, lemon) and/or chemesthesis which mediates pungent sensations (tingling, burning, etc) in response to substances such as ammonia. Responses transmitted by the olfactory nerve elicit aroma. Many compounds are pungent at high concentrations. Many compounds detected by chemesthesis via trigeminal nerve stimulation are strong nasal, ocular and throat irritants (Cometto-Muniz et al., 1997, 1998). There are a number of factors which affect odor including the volatile compounds themselves, the number of olfactory receptors available to bind them, the degree to which the compounds become solvated for receptor binding, temperature, humidity, and the matrix in which the odor-producing chemicals are embedded. In addition, individual chemicals may interact (chemically). Odors vary in threshold, intensity and hedonic tone. Measuring odor intensity alone is insufficient to assess human perception of odor (Misselbrook et al., 1993).

The measurement of airborne volatile organic compounds (VOCs) within and surrounding livestock production facilities has been the subject of extensive research in the past decade (O'Neill and Phillips, 1992; Hobbs et al., 1995, 1997; Zahn et al., 1997; Burton et al., 1998; Kim-Yang et al., 2001). Of particular importance has been the characterization and measurement of key potent odorants responsible for the unpleasant odor associated with these facilities and their waste steams, including air emissions. Short-chain volatile fatty acids (VFAs), phenols, amines, indoles and sulfur-containing compounds are the predominant classes of VOCs associated with swine production facilities (Spoelstra, 1980; O'Niell and Phillips, 1992; Hobbs et al., 1997; Zahn et al., 1997; Mackie et al., 1998; Zhu et al., 1999). Accurate measurement of these compounds and their odor impact have been challenging because VOCs possess widely varying physical and chemical properties and are present at concentrations ranging from high parts-per-million (ppb) to low parts-per-billion (ppb). Furthermore, each odorant has a unique odor and odor detection threshold which means that compounds, even if present at the same concentration, may have markedly different odor impacts.

Monitoring odors can be accomplished in several ways: chemical analyses, electronic methods and dynamic dilution olfactometry which takes advantage of the human sensory response. With the current state of technology, the best way to measure odors from livestock facilities is through use of human panels and gas chromatography/mass spectrometry (NPPC, 1998). This paper discusses the use of various instrumental and objective sensory-based techniques for the measurement of VOCs and odors associated with swine production operations.

Air Sampling and Gas Chromatographic Analysis

Instrumental methods have relied mainly on the application of gas chromatography (GC), including gas chromatography-mass spectrometry (GC-MS), since this mature separation technology is capable of the efficient separation required for analysis of complex mixtures of VOCs. In gas chromatography a mixture of volatile substances is injected into a column which separates the compounds based on their relative vapor pressures and polarities. The compounds are then detected as peaks which have specific retention times and peak areas which can be used for qualitative and quantitative determinations, respectively.

The main problem or consideration associated with use of gas chromatography has been the requirement of an extraction or preconcentration step. VOCs are most often isolated by taking advantage of their volatility and nonpolar nature. For analysis of airborne VOCs this generally means the use of an adsorbent trap, which allows for the selective enrichment (trapping) of the VOCs away from the bulk of the atmospheric gases and water vapor. The VOCs contained in the adsorbent trap are then transferred via thermal desorption, which releases the compounds from the trap and sends them to the gas chromatograph for analysis.

Over the past four years we have employed trapping techniques for analysis of air-borne VOCs emitted from swine finishing buildings. For in-the-field studies we have utilized portable air sampling devices in which the air is drawn through an adsorbent tube using vacuum pump at a fixed flow rate (e.g. 20 mL/min). In the literature various trapping agents, e.g. Tenax™ and graphitized carbons, have been shown to be effective for the isolation of airborne VOCs (Krzymien et al., 1999; Smet et al., 1999; Kim-Yang et al., 2001; Zahn et al., 2001; Zhang et al., 2001). Based on our experience, mixed-bed graphitized carbon traps are an excellent choice, since they allow for isolation of VOCs having widely varying volatilities and polarities, while at the same time, these traps minimize water vapor absorption which can perturb the thermal desorption step by causing blockage (ice) of the cryogenic trap of the gas chromatograph. However, occasionally even these traps can have moisture problems, such as when field sampling is done under very humid or extremely cold conditions. To overcome this problem we now use Tedlar™ bags for the primary field sampling. The bag sample is then brought back to the laboratory where the airborne VOCs are transferred from the bag onto an adsorbent trap using a vacuum pump under controlled conditions which minimize moisture sorption on the trap. This approach had been previously reported by Zhang et al. (2001). The above method offers an additional advantage since the same bag samples can be used for dynamic dilution olfactometry.

A typical gas chromatogram of VOCs collected from a swine finishing chamber is shown in Figure 1. In this case, gas chromatography was performed using both a nonspecific, broad spectrum flame-ionization detector and a sulfur-selective flame photometric detector. Gas chromatography-mass spectrometry is applied during the early stages of method development to aid in compound (peak) identification. The use of duel detectors for routine monitoring allows for the simultaneous analysis of key swine odor components found in relatively high concentrations (e.g. volatile short-chain fatty acids and phenols by flame ionization detection) and those found at trace levels (e.g. sulfur-containing compounds by flame photometric detection). The trace level sulfur-containing compounds are of particular importance because they often have very low odor detection thresholds and possess noxious odor properties.

Gas Chromatic Analysis of Liquids and Solids

For liquid or solid samples a large number of sample preparation strategies may be employed prior to gas chromatographic analysis. These include direct solvent extraction, purge-and-trap and solid phase microextraction (SPME) among many other techniques. Purge-and-trap involves the continuous removal (entrainment) of VOCs from a thermostatted sample using a stream of inert gas (e.g. N_2). The VOCs contained in the gas stream are then enriched on an adsorbent trap and then analyzed by thermal desorption-gas chromatography as discussed above for air sampling. The relatively new solid phase microextraction represents a rapid, solventless technique that is based on the partitioning of the volatile components between the sample or the sample headspace and a polymer-coated fiber. For analysis, the volatiles are thermally desorbed from the fiber in the heated injector port of the GC. Solid-phase microextraction-gas chromatography offers the advantage of high sample throughput since this method can be performed by modern automated multipurpose samplers. The technique has been applied for the analysis of swine VOCs (Rizzuti et al., 1999; Yo, 1999).

Figure 2 shows a typical gas chromatogram of volatile constituents of a swine manure sample analyzed by solid-phase microextraction-gas chromatography. Prior to the analysis the sample was spiked with known amounts of two surrogate internal standards to aid in quantification of key odorants (i.e., 2-ethylbutanoic acid was used for volatile short-chain fatty acids; and 4-tert-amylphenol for phenolic and indolic compounds). In addition, the sample is mixed with a matrix modifier, which serves to stabilize the pH (necessary for analysis of volatile acids, phenols and indoles since their dissociation is affected by pH) and to minimize the protein or lipid binding of the volatile constituents by a salting out (high NaCl concentration) effect. Details of the analysis are given in the caption of Figure 2. Typical quantitative results for a manure sample are shown in Table 1. These concentration levels are in general agreement with other published reports on the volatile composition of swine manure and slurries (Chen et al., 1994; Zahn et al., 1997).

We also have applied the above methodology to the analysis of wastewater and dust samples originating from swine finishing buildings. A representative gas chromatogram of a dust sample is shown in Figure 3, which indicates the presence of several aldehydes (e.g. hexanal, heptanal, etc.) originating from the feed in addition to the usual volatile constituents of swine manure (Hammond et al., 1979).

Electronic Noses

The electronic nose is an instrument that consists of an array of electronic chemical receptors which detect volatile chemicals or categories of chemicals then usees the information to predict sensory-like properties. Electronic noses contain an array of sensors (sintered metal oxides, catalytic metals, conducting polymers, lipid layers, phtholocyanins, organic semi-conductors, surface acoustic wave or combinations) which respond to a wide variety of chemical classes (Strassburger, 1996). The sensors are based on conducting composites that change resistance on exposure to a vapor (Feast, 2000). The change in resistance (ΔR) of individual sensors from baseline resistance (R) produces a pattern of resistance changes ($\Delta R/R$) across the array (Misselbrook et al., 1997). The measured response is then converted to a signal using a

computer processor. To identify the type, quantity, and quality of the odor the computer uses changes in the pattern generated in the entire sensory array (Figure 4). Metal oxide arrays require very high temperatures to operate, and the polymer sensors don't detect small amines and thiols responsible for fishy, skunky and rotten-egg odors (really smelly substances). New sensors using inks based on organometallic compounds change color when bound by vapor molecules (like heme iron in hemoglobin which becomes bright red when it reversibly binds oxygen; Schmiedeskam, 2001).

All of these sensors (and their combinations) vary in the magnitude of response to any one compound giving them the discriminatory ability required to analyze odors. The volatile sample is injected, in combination with filtered air, such that it can flow over and interact with the sensors. An output signal is generated as a result of the change in resistance at the sensory surface as a result of its interaction with compounds in the gas phase. The binding and resistance change are rapid and temporary. Response data are exported to a computer which has been trained to use chemometric and "artificial neural network" computer software as a way to recognize the pattern of a mixture of compounds as a specific odor and to discriminate slight differences. Because very large amounts of data are generated, processing it into useful information requires statistical analysis software which can conduct principal component analysis and discriminant factor analysis.

Use of arrays of non-specific sensors allows for detection of many thousands of chemical species due to the broad selectivity of the sensory surfaces. The electronic nose can measure a complex group of substances (like the human olfactory system) very rapidly (10-120 seconds), and it can be trained to discriminate "good" from "bad" aromas. However, the electronic nose must be trained for each important component (grassy, smoky) for each application, it must be standardized by both chemical and olfactometric methods, and the "sensor array" is restricted. One of the biggest challenges for electronic noses is detecting complex odors against an intricate background matrix.

While the above instrumental methods do offer the potential for the accurate estimation of VOC levels in waste streams and air emissions associated with swine production facilities, they do not, however, allow for the direct measurement of odor intensity nor odor quality. For this purpose, researchers have relied on the use of subjective and objective sensory analysis using human panelists. Foremost among these techniques is dynamic dilution olfactometry.

Dynamic Dilution Olfactometry

Dynamic Dilution Olfactometry (DDO) is based on "dilution to threshold" of a gas sample containing multiple components. Odor threshold is a commonly used term. In general, it is the minimum concentration detectable or the minimum detectable difference between two concentrations (ASTM, 1997a). Because of additive / subtractive effects (of individual chemicals) in mixed systems, the threshold for a particular compound may not be useful. Thresholds for different substances can be several orders of magnitude different, and thresholds for different people can be several odors of magnitude different.

An odor threshold (minimum detectable amount) can be measured in "known" samples (standards) and expressed as "X ppm of compound Y" (in air). To conduct a dilution-to-threshold test, the gas containing the volatile chemical is collected in a bag, then a known volume is injected through a flow-splitter where air is used to dilute it to selected ratios. The dilutions are usually factors of 2 or 3. The more the gas must be diluted with pure air to lower it to the Detection Threshold, the stronger the odor of the gas. For a pure compound, the dilution corresponds to the concentration:

$$1 \text{ ppm} = 1/1{,}000{,}000 = 10^{-6} \text{ dilution} = \text{dilution factor "6"}$$

In this case, odor intensity is a function of concentration (Figure 5). "Stevens Power Law" (Stevens, 1957) states that the apparent magnitude of intensity grows as a power function of the stimulus magnitude which implies that equal ratio changes in sensation magnitude correspond to equal changes in the stimulus magnitude:

$$I = k\,(C)^{n}$$

where C is the odorant concentration, and k and n are constants that differ for each odor. Therefore, for a pure compound, if we know the power function and the concentration, we can determine the intensity. A derivative of this relationship is the log function of the concentration of the odorant.

Determining Detection Thresholds of "unknown" complex mixtures (barn air) is much more difficult because (1) we don't know what compounds are present, and (2) we don't know their concentrations. No instrument is available to quickly measure the concentration of odors consisting of many compounds. One way around this problem is to express the odor strength as "odor units". The odor unit is a calculated value based on the Threshold Dilution ratio and the concentration:

$$Z = C / Cs$$

where Z is the Threshold Dilution ratio measured by an olfactometer (as with a pure compound), C is the odor concentration and Cs is the theoretical minimum concentration of the odor for detection in 50% of the population. To calculate odor units, "Z" must be determined for the unknown sample while C and Cs are determined using a pure substance (standard; n-butanol). The "strength" of the odor is expressed in dimensionless "odor units" which are calculated as the -log of the dilution at which the odor can be detected which may be adjusted for the concentration and the detection threshold of a known substance. For example, if odor is detected at a dilution of 1 part barn air to 27 parts purified air:

Dilution Threshold (ratio) = Volume of pure air / Volume of odorous air

Dilution Threshold ratio = 27/1

DDO requires a panel of 3-10 people who determine how much a sample of air must be diluted before they can no longer smell it. An air sample, most often 10 L, is collected in a bag made of

relatively inert material (Tedlar). The odor mixture is diluted with purified air then presented to pre-selected sensory panelists at several dilutions. For each dilution, the panelist is presented with three samples two of which are the same. The panelist then makes a "forced choice" among three alternatives selecting the sample which is different Very dilute samples are presented at the beginning of the test, increasing in concentration after every set of three. At some point in the series of concentrations, each panelist will become able to detect the odor. The Best Estimate Threshold (BET), the halfway point between the dilution where odor can be detected and that where it can't be detected, is calculated as the square root of the product of those two dilution factors m=(ASTM 1990, 1997b). If the odor is detected at the 27/1 dilution but not at the 81/1 dilution, then:

$$\mathbf{BET = \sqrt{(27 \times 81)} = 46.77}$$

The BET value for each panelist is determined. The log of each value is calculated. The logs of the individual BETs are averaged to produce a "geometric mean". This geometric mean is similar to the log of the dilution factor for a pure compound (such as n-butanol). The antilog of the BET geometric mean is the average "concentration" (or average Dilution Threshold ratio for mixed samples) at which the group can "detect" the odor (Figure 6).

The panel response to the mixed sample may be expressed in Odor Units (OU) which are simply the Dilution Threshold Ratio, the Dilution Threshold Ratio adjusted for the concentration at the Detection Threshold for a known amount of a pure standard, or the amount of odorant in one cubic meter (OU/cm3). The European Odor Unit (OU_E) is defined in terms of N-butanol (AWME EE-6, 2002)

To calculate the European Odor Units:

1. Determine concentration of n-butanol at its Odor Detection Threshold (ODT_b). This is the Odor Detection Concentration for n-butanol (ODC_b).

2. Determine the Odor Units for the "mixed sample": this is the Odor Detection Threshold of the unknown sample adjusted to the Odor Detection Concentration for n-butanol

   $OU_E = (ODT \ X \ ODC_b) / 40$ ppb

   OU_E = European Odor Units
   ODT = Odor detection threshold (ratio) of the sample
   ODC_b = Odor concentration of n-butanol at its detection threshold
   40 ppb= the "definition" of 1 OU_E in terms of n-butanol

European standards require that ODC_b be between 20 and 80 ppb for each panelist, so panelists are screened prior to their participation in an olfactometry panel. One "European Odor Unit" is 123 mg n-butanol (40ppb) by definition so, if we determine the ODC_b to be other than 40, we must adjust our ODT accordingly.

If we determined that our actual Odor Detection Threshold for n-butanol is 50ppb, we must adjust the Odor Detection Threshold of our unknown:

$$OU_E = (ODT) \times ODC_b / 40$$
$$OU_E = (25.7) \times 50 / 40$$
$$OU_E = 32.13$$

Dilution olfactometry will give an indication of the overall strength of the odor in terms of how much must be present to detect it, and it will give "numbers" for comparison (across time, intervention methods, etc.), however it gives no indication of odor strength at suprathreshold amounts. Dilution olfactometry will not identify individual odors, it will not give an idea of which compounds contribute most to a complex odor, and it will not give "hedonic" information (good / bad smell). Unless the DDO data are correlated with a sensory "intensity" reference scale (1 = very weak, 5 = very intense) using reference odorant concentrations, DDO data alone do not give an indication of how intense the odor is.

The primary advantage of DDO is that the human nose is the actual detector—it is the most sensitive detector for many compounds. The disadvantage is that is cumbersome for use outside a laboratory environment. It depends on using panelists who have (1) been selected for their sensitivity in a specific range, and (2) have been "standardized" to a specific concentration of a specific concentration of a specific compound (usually n-butanol). DDO determines odor threshold, not "odor quality" (smells like lemon, cinnamon, etc.).

The "odor unit" seems to be the most common index for odor emission control. A number of states in the US have a source emission standard. However, there are problems with using the odor unit as a standard: (1) because of the variability of people, who serve as the detectors for generation of the odor unit, data vary from laboratory-to-laboratory, and (2) the odor unit includes *no measure of the importance of the odor.*

REFERENCES

ASTM. 1990. Standard Method for Defining and Calculating Sensory Threshold from Intermediate Size. ASMA E 18.04.25 Sensory Thresholds from Forced-Choice Data, 6th Draft--April, American Society for Testing and Materials, West Conshohocken, PA.

ASTM. 1997a. Standard practice for referencing suprathreshold odor intensity. ASTM E544-75. American Society for Testing and Materials, West Conshohocken, PA.

ASTM. 1997b. Standard practice for determination of odor and taste thresholds by a forced-choice ascending concentration series method of limits. ASTM E679-91. American Society for Testing and Materials, West Conshohocken, PA.

AWMA EE-6 Subcommittee on the Standardization of Odor Measurement. 2002. Guidelines for odor sampling and measurement by dynamic dilution olfactometry. Submitted for Review to: ASTM E18 Sensory Committee-- August. American Society for Testing and Materials, West Conshohocken, PA

Burton, C.H., R.W. Sneath, T.H. Misselbrook, and B.F. Pain. 1998. The effect of farm scale aerobic treatment of piggery slurry on odour concentration, intensity and offensiveness. J. agric. Engng Res. 71:203-211.

Chen, A., P.H. Liao, and K.V. Lo. 1994. Headspace analysis of malodorous compounds from swine wastewater under aerobic treatment. Bioresource Technol. 49:83-87.

Chen, Y., D.S., Bundy, and S.J. Hoff. 1999. Development of the relationship between odor intensity and threshold dilution ratio for swine units. Journal of Air and Waste Manag. Assoc. 49:1082-1088.

Chen, Y., D.S. Bundy, and S.J. Hoff. 1999. Using olfactometry to measure intensity and threshold dilution ratio for evaluating swine odor. Journal of Air and Waste Manag. Assoc. 49:847-853.

Cometto-Muniz, Cain, W.S. and M.H. Abraham. 1998. Nasal pungency and odor of homologous aldehydes and carboxylic acid. Ex. Brain Res. 118:180-188.

Cometto-Muniz, Cain, W.S. and H.K. Hudnell. 1997. Agonistic sensory effects of airborne chemicals in mixtures: odor, nasal pungency and eye irritation. Perception and Psychophysics. 59(5): 665-674.

Feast, S. 2000. Odor detection technology for characterizing the state of chemical systems. American Laboratory. March. Pp. 38-42.

Hammond, E.G., C. Fedler, and G. Junk. 1979. Identification of dust-borne odors in swinw confinement facilities. Transactions of the ASAE 22:1186-1189, 1192.

Hobbs, P.J., T.H. Misselbrook, and B.F. Pain. 1995. Assessment of odours from livestock wastes by a photoionization detector, an electronic nose, olfactometry and gas chromatography-mass spectrometry. J. agric. Engng Res. 60:137-144.

Hobbs, P.J., T.H. Misselbrook, and B.F. Pain. 1997. Characterisation of odorous compounds and emissions from slurries produced from weaner pigs fed dry feed and liquid diets. J. Sci. Food Agric. 73:437-445.

Heber, A., T. Lim, J. Ni, D. Kendall, B. Richert, and A. Sutton. 2001. Odor, ammonia and hydrogen sulfide emission factors for grow-finish buildings (#99-122). Final Report to National Pork Producers Council. Clive, IA.

Kim-Yang, H., S. Davies, R.D. von Bernuth, and E.A. Kline. 2001. A comparison of sampling methods for the characterization of odorous compounds in livestock facilities using gas chromatography – mass spectrometry. Paper 01-4037. ASAE Annual International Meeting, Sacramento, CA, July 30-Aug 1.

Kryzmien, M., M. Day, K. Shaw, and L. Zaremba. 1999. An investigation of odors and volatile organic compounds released during composting. J. Air & Waste Manage. Assoc. 49:804-813.

Mackie, R.I., P.G. Stroot, and V.H. Varel. 1998. Biochemical identification and biological origin of key odor components in livestock waste. J. Anim. Sci. 76:1331-1342.

Misselbrook, T.H., Clarkson, C.R. and Pain, B.F. 1993. Relationship between concentration and intensity of odours for pig slurry and broiler houses. J. Ag. Engng. Res. 55(2):163-169.

Misselbrook, T.H., Hobbs, PJ., and Persaud, K.C. 1997. Use of an electronic nose to measure odour concentration following application of cattle slurry to grassland. J. Agric. Engng. Res. 66:213-220.

National Pork Producers Council. 1998. Electronic nose researched for odor evaluations. TechTalk, NPPC, Des Moines, IA. Spring.

O'Neill, D.H. and V.R. Phillips. 1992. A review of the control of odour nuisance from livestock buildings: Part 3, properties of the odorous substances which have been identified in livestock wastes or in the air around them. J. agric. Engng Res. 53: 23-50.

Rizzuti, A.M., A.D. Cohen, P.G. Hunt, and M.B. Vanotti. 1999. Evaluating peats for their capacities to remove odorous compounds from liquid swine manure using headspace "solid-phase microextraction". J. Environ. Sci. Health, B34(4): 709-748.

Schmiedeskam, M. 2001. Plenty to sniff at. Scientific American. March. http://www.sciam.com/2001/0301issue/0301techbus1.html.

Schulte, D.D. Odors—What are they and how are they measured. Manure Matters Vol. 6(3).

Smet, E., H. Van Langenhove, and I. De Bo. 1999. The emission of volatile compounds during the aerobic and the combined anaerobic/aerobic composting of biowaste. Atmospheric Environ. 33:1295-1303.

Spoelstra, S.F. 1980. Origin of objectionable odorous components in piggery wastes and the possibility of applying indicator components for studying odour development. Agric.Environ. 5:241-260.

Strassburger, K.J. 1996. Electronic nose evaluation in the flavor industry—it really works! Food Testing and Analysis. October/November, pp. 22-27, 37.

Stevens, S.S. 1957. On the psychophysical law. Psychophysical Rev. 64: 153-181

Van den Dool, H. and P.D. Kratz. 1963. Generalization of the retention index system including linear temperature programmed gas-liquid partition chromatography. J. Chromatogr. 11: 463-471.

Yo, S.-P. 1999. Analysis of volatile fatty acids in wastewater collected from a pig farm by a solid phase microextraction method. Chemosphere 38: 823-834.

Zahn, J.A., J.L. Hatfield, Y.S. Do, A.A. DiSperito, D.A. Laird, and R.L. Pfeiffer. 1997. Characterization of volatile organic emissions and wastes from a swine production facility. J. Environ. Qual. 26:1687-1696.

Zahn, J.A., J.L. Hatfield, D.A. Laird, T.T. Hart, Y.S. Do, and A.A. DiSpirito. 2001. Functional classification of swine manure management systems based on effluent and gas emission characteristics. J. Environ. Qual. 30: 635-647.

Zhang, J., K.M. Keener, R.W. Bottcher, and R.D. Munilla. 2001. Measurement of artificial swine odorants in the vapor phase. Paper 01-4036. ASAE Annual International Meeting, Sacramento, CA, July 30-Aug 1.

Zhou, Q., C.L. Wintersteen, and K.R. Cadwallader. 2002. Identification and quantification of aroma-active components that contribute to the distinct malty flavor of buckwheat honey. J. Agric. Food Chem. 50: 2016-2021.

Zhu, J., G.L. Riskowski, and M. Torremorell. 1999. Volatile fatty acids as odor indicators in swine manure – A critical review. Transactions of the ASAE 42: 175-182.

Zahn, J.A., A.A. DiSpirito, Y.S. Do, B.E. Brooks, E.E. Cooper and J.L.Hatfield. 2001. Correlation of human olfactory responses to airborne concentrations of malodorous volatile organic compounds emitted from swine effluent. J. Environ. Qual. 30:624-634.

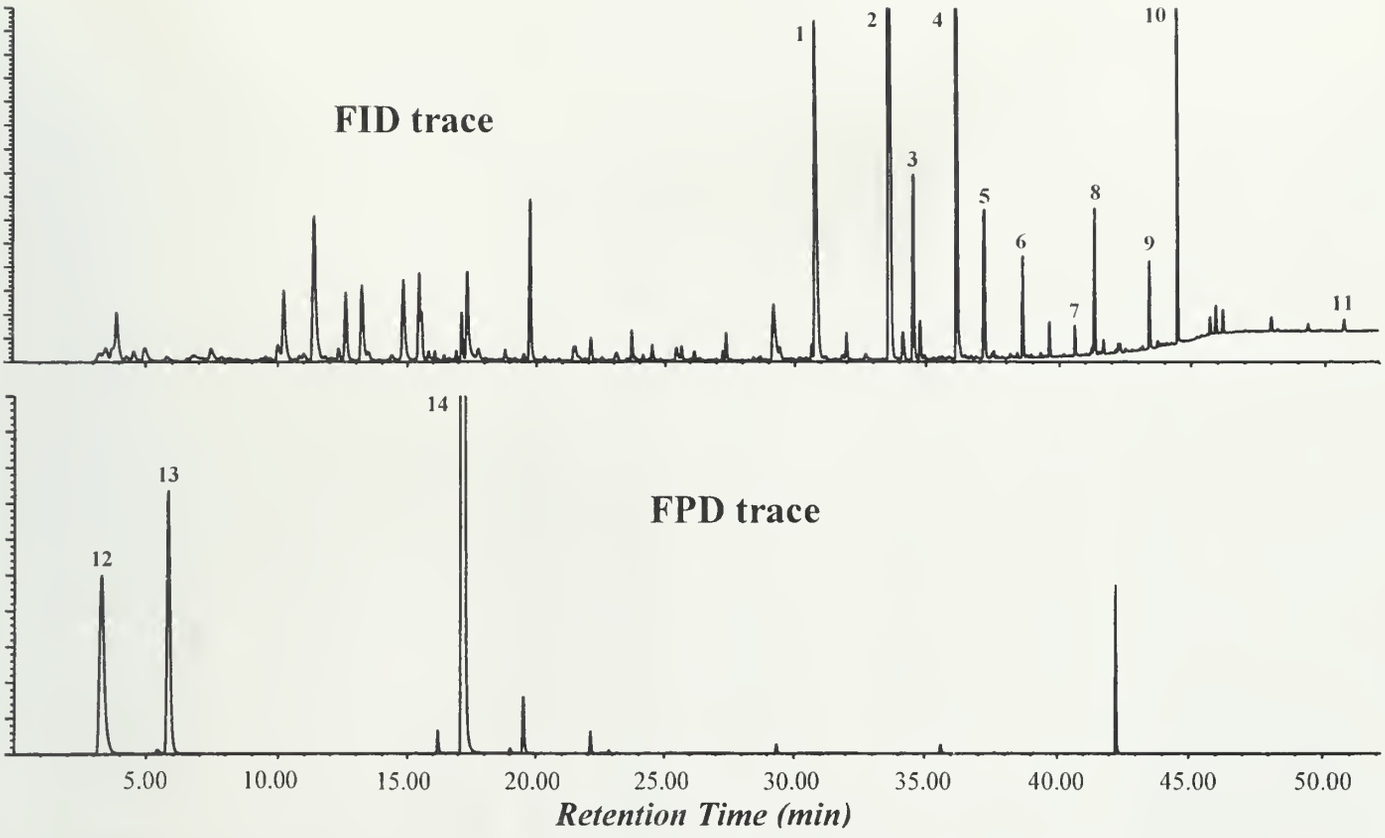

Figure 1. Gas chromatograms of air-borne volatile organic compounds collected via a Tedlar™ bag from air emitted from a swine finishing building; FID trace = flame ionization detector, FPD trace = flame photometric detector. (**1** = acetic acid, **2** = N,N-dimethylacetamide {artifact from Tedlar™ bag}, **3** = 2-methylpropanoic acid, **4** = butanoic acid, **5** = 2-/3-methylbutanoic acid; **6** = pentanoic acid, **7** = hexanoic acid, **8** = heptanoic acid, **9** = phenol, **10** = 4-methylphenol {*p*-cresol}, **11** = indole, **12** = methanethiol, **13** = dimethylsulfide, **14** = dimethyldisufide). [***Purge and Trap-Thermal Desorption-GC.*** VOCs were collected on 1/4 in. glass Carbotrap 300 multi-bed adsorbent tubes (Supelco, Bellefonte, PA) by drawing air through trap at a rate of 100 mL/min using a vacuum pump for 20 min. Gas chromatographic (GC) analysis was performed using a TDSA automated thermal desorption system (Gerstel, Germany) connected to an Agilent 6890 GC (Agilent Technologies, Inc.) system equipped with flame ionization (FID) and flavor photometric (FPD) detectors. Each trap was dry purged for 20 min (helium at 50 mL/min) at 30°C to remove moisture from the trap and then the VOCs were thermally desorbed (300°C for 5 min; 50 mL/min, helium flow) and subsequently cryofocused (-150°C) in a CIS 4 programmable temperature vaporizer inlet (Gerstel). Cryofocused volatiles were thermally desorbed (280°C) directly into the analytical GC column. Between analyses traps were reconditioned at 300°C for 30 min under a flow of helium (100 mL/min). Separations were performed on a DBWAXetr column (50 m length x 320 μm i.d. x 1 μm film thickness; J&W Scientific, Folson, CA). GC column effluent was split 1:1 between FID and FPD using deactivated fused silica tubing (1 m length, 250 μm i.d.). Oven temperature was programmed as follows: 40°C (5 min initial hold), ramped at 4°C/min to 155°C, ramped at 8°C/min to 250°C (21.5 min final hold). GC peak identifications were made by comparing data from GC-mass spectrometry and retention indices (Van den Dool and Kratz, 1963) with those of authentic standard compounds. GC peak areas were determined using HP Chemstation software.]

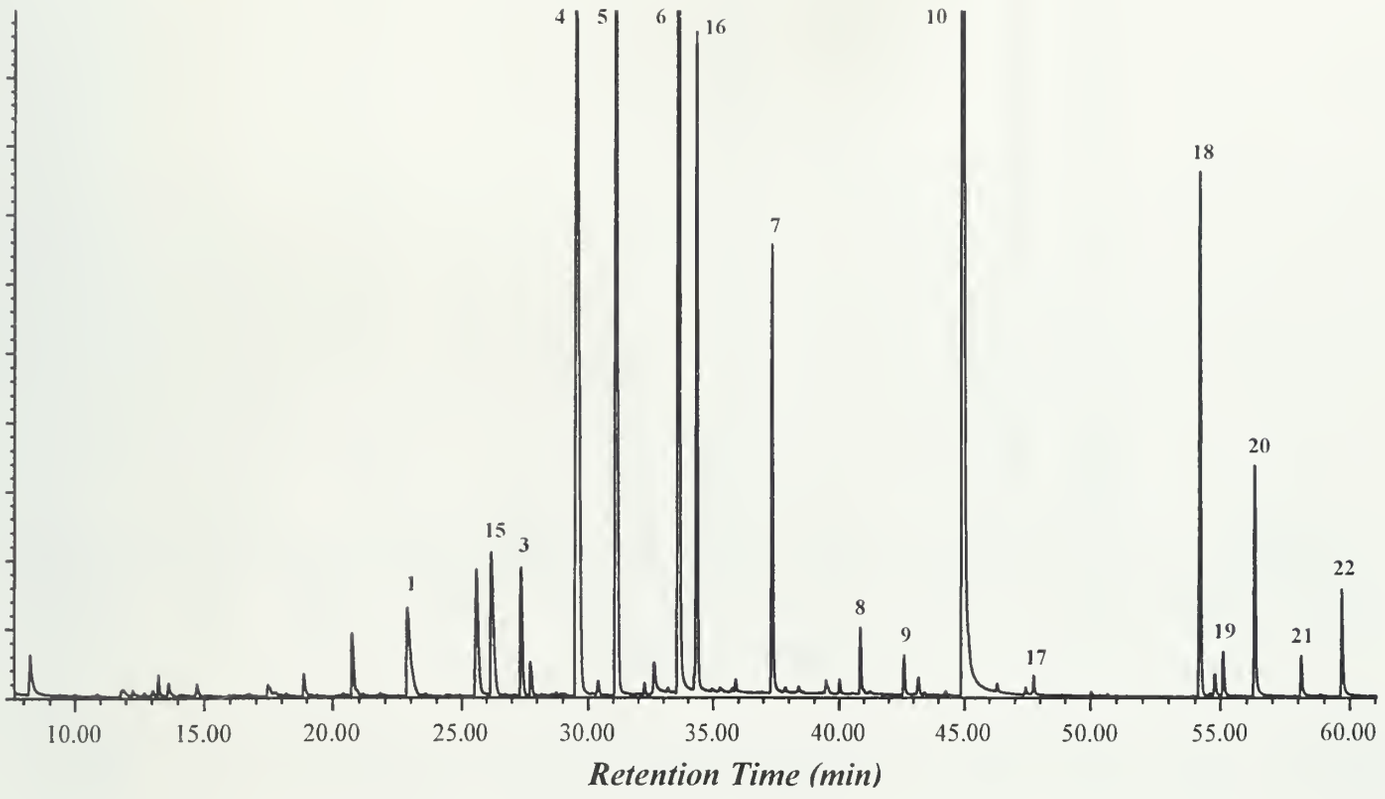

Figure 2. Headspace SPME-GC-MS profile of a swine manure sample. (**1** = acetic acid, **15** = propanoic acid, **3** = 2-methylpropanoic acid, **4** = butanoic acid, **5** = 2-/3-methylbutanoic acid; **6** = pentanoic acid, **16** = IS_1 = 2-ethylbutanoic acid, **7** = hexanoic acid, **8** = heptanoic acid, **9** = phenol, **10** = 4-methylphenol {*p*-cresol}, **17** = 4-ethylphenol, **18** = IS_2 = 4-*tert*-amylphenol, **19** = indole, **20** = 3-methylindole {skatole}, **21** = benzeneacetic acid, **22** = benzenepropanoic acid). [***Sample Preparation.*** Sample (1 g) plus 5 mL of a matrix modifier solution (deodorized 2 M aqueous citrate-phosphate buffer, pH 5, saturated with NaCl) and 5 µL of internal standard solution (1.19 mg/mL of *tert*-amylphenol and 13.4 mg/mL of 2-ethylbutanoic acid in methanol) was transferred to a 22-mL glass headspace vial and the vial was sealed with a Teflon-faced silicon septum. ***Headspace-Solid Phase Microextraction-Gas Chromatography (H-SPME-GC).*** Analysis system consisted of an Agilent 6890 GC (Agilent Technologies, Inc., Palo Alto, CA) equipped with a flame ionization detector (FID) and MPS2 (SPME mode) autosampler (Gerstel, Germany). For SPME, vial was preinclubated at 60°C for 10 min with agitation (500 rpm, 5 s on, 2 s off). Then a SPME fiber (Carboxen/polydimethylsiloxane fiber, Supelco, Bellefonte, PA) was exposed to the vial headspace for an additional 20 min. Immediately after sampling, the fiber was desorbed by splitless injection (injector temperature 260°C; splitless time 4 min; split vent flow 50 mL/min) into a Stabilwax® DA GC column (15 m x 0.32 mm i.d. x 0.5 µm film; Restek, Bellefonte, PA). GC oven temperature was programmed from 35 to 225°C at a rate of 10°C/min with initial and final hold times of 5 and 10 min respectively. For qualitative analysis an Agilent 5973 mass selective (MS) detector was used as the GC detector. Compounds were identified by comparison of their mass spectra and retention indices (Van den Dool and Kratz, 1963) with those of reference standards.]

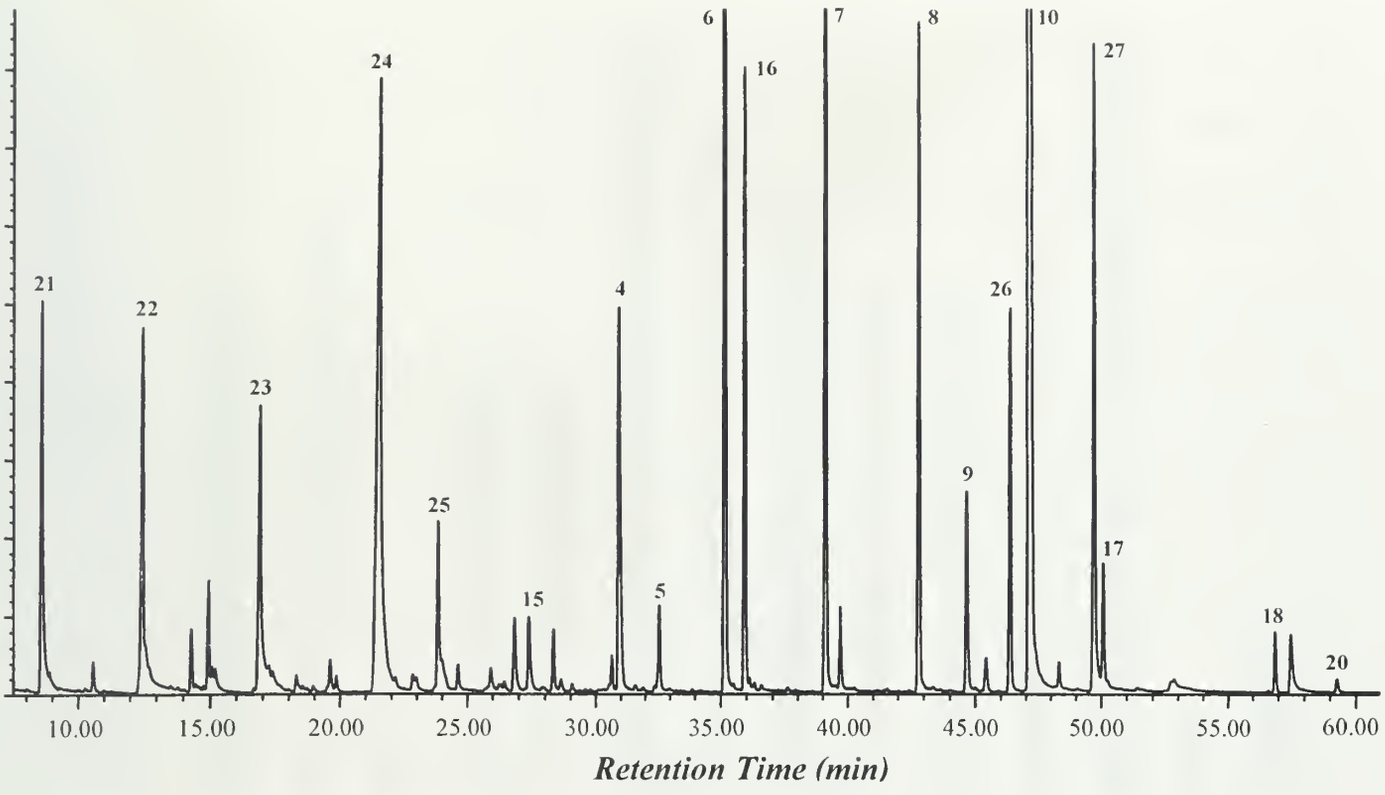

Figure 3. Typical headspace SPME-GC-MS profile of dust collected from a swine production facility. (**21** = hexanal, **22** = heptanal, **23** = octanal, **24** = nonanal, **25** = 1-octen-3-ol, **15** = propanoic acid, **4** = butanoic acid, **5** = 2-/3-methylbutanoic acid; **6** = pentanoic acid, **16** = IS_1 = 2-ethylbutanoic acid, **7** = hexanoic acid, **8** = heptanoic acid, **9** = phenol, **26** = octanoic acid, **10** = 4-methylphenol {*p*-cresol}, **27** = nonanoic acid, **17** = 4-ethylphenol, **18** = IS_2 = 4-*tert*-amylphenol, **20** = 3-methylindole {skatole}). [One gram sample analyzed by the method described in Figure 3 caption.]

Figure 4--Electronic Nose Sensor Response to Odorant

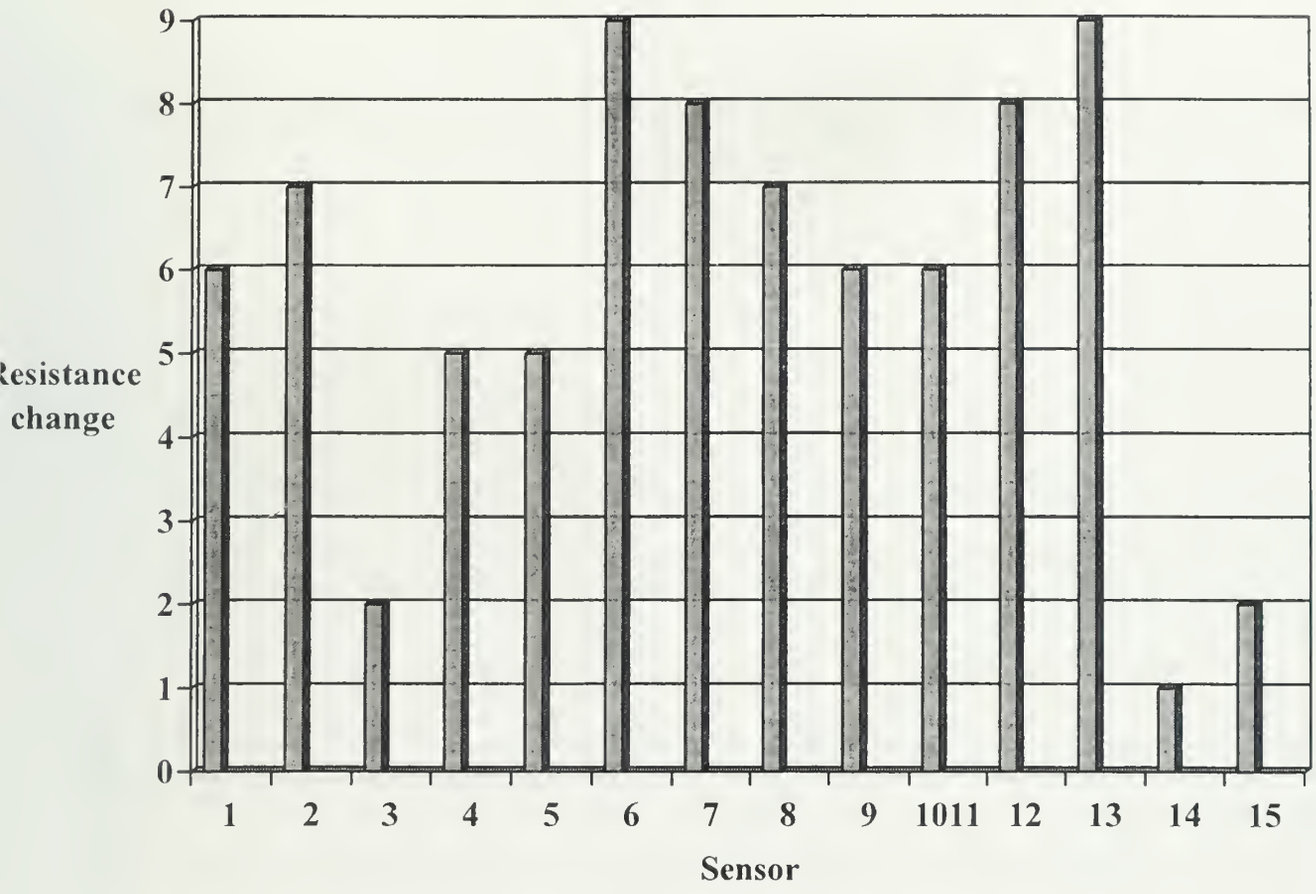

Figure 5--Relationship of Odor Strength of a Pure Compound to Dilution Factor

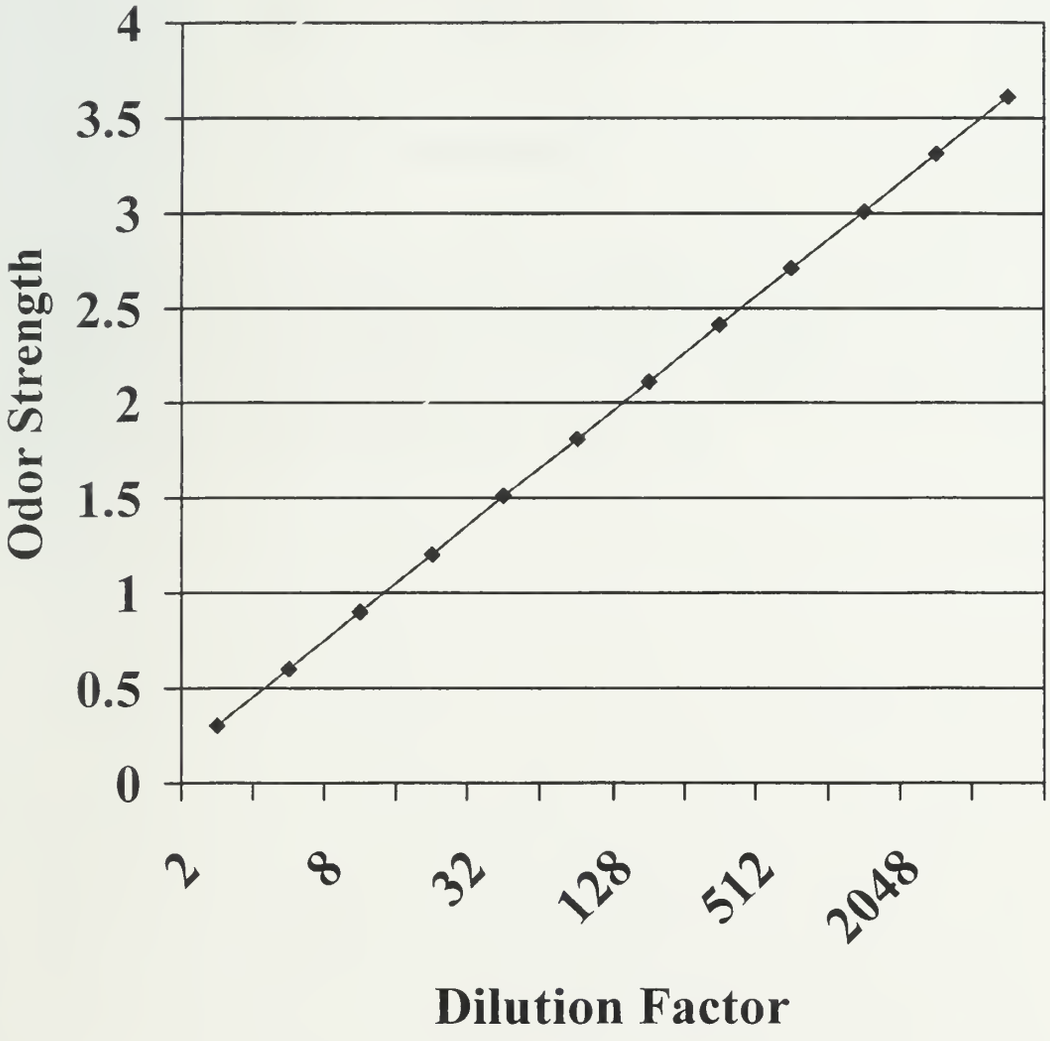

Figure 6--Calculation of Odor Threshold from 3-Alternative Forced Choice Data Determined by Olfactometry

Judge	Dilutions									
	Dilution Factors (concentrations increase →)								**Best Estimate Threshold (BET)**	
	8	7	6	5	4	3	2	1		
	256	128	64	32	16	8	4	2	Value	$\log_{10}$ of value
1	0	0	0 *	+	+	+	+	+	45.25	1.65
2	+	0	+	0 *	+	+	+	+	22.62	1.35
3	0	+	0	0	0 *	+	+	+	11.31	1.05
4	0	0	0 *	+	+	+	+	+	45.25	1.65
5	0	0	0	0	0	0 *	+	+	5.65	0.75
6	0	0 *	+	+	+	+	+	+	90.51	1.96
									$\Sigma\log_{10}$	8.41
									Mean	1.41
Group BET Geometric Mean									**25.70** ←	Antilog 1.41

"0" indicates that judge selected the wrong sample from the set of three
"+" indicates that judge selected the correct (different) sample
"Value" is the half-way point between the dilutions where the judge was and was not (*) able to select the correct sample
"BET" is the Best Estimate Threshold = $\sqrt{([+] \times [-])}$

Table 1. Concentrations for Selected Odorants in a Swine Manure Sample

No.[a]	Compound	Concentration (ug/g)[b]
1	Acetic acid	561
15	Propanoic acid	1080
3	2-Methylpropanoic acid	167
4	Butanoic acid	2010
5	2-/3-Methylbutanoic acid	587
6	Propanoic acid	740
7	Hexanoic acid	158
9	Phenol	111
10	4-Methylphenol (p-cresol)	1180
17	4-Ethylphenol	13.2
19	Indole	1.8
20	3-Methylindole (skatole)	10.8
21	Benzeneacetic acid	6.1
22	Benzenepropanoic acid	14.1

[a] Numbers correspond to those in Figures 1-3. [b] Average (n = 2) concentration by H-SPME-GC [***Quantification of Volatile Compounds.*** GC-FID response factor (f_i) for each compound was determined by addition of known amounts of reference standards into 5-mL of matrix modifier solution containing 1 mL of deodorized water prior to analysis. Sample preparation and GC-FID analysis were performed in the same way as described above for samples, with the assumption that the extraction recoveries of individual volatile compounds in this matrix were similar to those in the sample matrix. FID response factors (f_i) were used to calculate actual concentrations according to Zhou et al. (2002). Internal standard *tert*-amylphenol was used to determine f_i values for phenol, 4-methylphenol and 4-ethylphenol, indole and 3-methylindole, and internal standard 2-ethylbutanoic acid was used for acetic, propanoic, isobutyric, butyric, 3-methylbutyric, pentanoic, hexanoic, phenylacetic and 3-phenylacetic acid.]

Atmospheric Dispersion and Aerosol Interactions of Swine Odor*

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INTRODUCTION

The work reported here has two separate focus areas. The focus of our dispersion modeling studies was to improve the description of odor transport to better account for effects of elevated sources, trees surrounding a hog facility, and terrain features such as ravines.

The second focus was the development of methods to calibrate an odor-measurement device developed throughout the SRI and operating procedures that assure the instrument yields reproducible results.

ODOR DISPERSION MODELING

Previous work of the effort on dispersion modeling of hog odor employed a Gaussian plume model to summarize odor transport with respect to distance, prevailing wind direction, and odor emission rate, to determine the frequency the ground-level odor is above the detection threshold at various distances from the source. This information is useful for estimating the impact of a hog facility in producing noticeable odors in the vicinity and in assessing the impacts of odor-control measures. The dispersion model also was extended to estimate the impact of elevated release of odor on ground-level concentrations.

The Gaussian plume model lacks the sophistication to address many questions that arise, such as the effect of vegetation in the vicinity of the facility. Questions that are of interest: To what degree could vegetation barriers reduce odor impact? What would be the optimal orientation of the barriers? Another issue that often arises in connection with odor complaints is the speculation that odor follows terrain features such as a ravines and is able to remain above the detection threshold for considerably longer transport distances under favorable atmospheric conditions.

To address these issues, two new approaches beyond use of a Gaussian dispersion model have been initiated to investigate different aspects of odor transport. *First*, a "micro" model was developed, by scaling-down a 3-D air-quality model, to resolve concentrations over spatial distances appropriate for the description of odor dispersion. The air-quality model has been extensively used at a horizontal resolution of 10 km and the corresponding

* Prepared for presentation at University of Illinois Pork Industry Conference, Champaign, IL, December 11-12, 2003.

resolution of the micro model is 100 m. In the vertical dimension the thickness of the lowest layer was scaled from 75 m to 1 m. The micro model describes pollutant transport and chemical transformation given the meteorological conditions.

For the odor problem, all chemical reactions are ignored because too little is known about the chemical transformation of odor components in the atmosphere.

Deposition of odor to surfaces is addressed in the micro model, but there is uncertainty concerning what deposition rate to use.

In order to compute the transport, a meteorological field describing the atmospheric motion must be input to the air-quality model. From other studies we have meteorological output from version 5 of the mesoscale meteorological model (MM5), a model widely used in the meteorological community, for summer months 1995. At present the micro model uses the MM5 output with the winds from MM5 extrapolated from the 10-km resolution grid to the100-m grids.

The *second approach* is to use Fluent, a computational fluid dynamics code, which resolves momentum, energy (temperature), and (optionally) species transport. Use of Fluent involves constructing a detailed (3-dimensional if desired) grid of the area to be modeled, specifying boundary conditions, and running the simulation to obtain convergence of the solution. One use of Fluent in the present context is to derive more precise meteorological fields for input to the micro model. Other applications are to derive meteorological and species dispersion fields in the vicinity of a hog facility to determine effects of tree barriers, elevated emissions, and a ravine. It presently appears that Fluent can be configured to take input from MM5 over the scale of 10 km and produce meteorological and species fields sufficiently detailed in the vicinity of features such as buildings, tree barriers, elevated stacks, and ravines. This is possible because the finite-element grid strategy employed in Fluent allows the grid to be fine in places where more detail is required and coarse at other areas in the model domain.

The practical question: Can the grid and model strategy be laid out with sufficient skill to meet these computational constraints yet not require excessive amounts of computer time? (An account was obtained on an NCSA supercomputer for the SOWM project with a fixed computer time allotment. The NCSA account affords access to Fluent which would otherwise be costly.)

An alternative is to use Fluent in a nested fashion. In the present case this involves running with a 10-km horizontal domain using input from MM5 to obtain meteorological and temperature fields at 100-m horizontal and approximately 1-m vertical resolution. This output could then be used to drive the micro model or to drive a nested Fluent model. The micro model source emissions from a building are specified by setting the concentration in the lowest grid cells (100 m x 100 m x 3 m) to a higher level (corresponding to the estimated building emission rate times the model time step of approximately 1 min) and setting initial concentration in surrounding grids to zero. An elevated stack emission is simulated in the micro-model by specifying an elevated grid (100 m x 100 m x 1m) at an increased concentration.

Fluent can be used as an emissions model to specify a building source as emanating from the sides of a building or an elevated source from a stack. The simulation could proceed to arrive at concentrations averaged over the micro model grid as a better approximation of a building or elevated source for the micro model. Simulations of the effect of trees or a ravine cannot be easily performed with the micro model. If the Fluent simulation over the entire 10-km domain cannot adequately resolve flow features over trees or a ravine in a single simulation, a smaller (~1-km) Fluent model can be nested to take boundary flow from the 10-km Fluent simulation in a two-step process.

Odor Measurement

The odor-measurement effort has shown promise as a tool for routine odor measurement. Odor is measured by determining the response of alkaline aerosol particles (typically NaOH) to the acids in swine odor. The method of detection that has shown most promise relies on operation of a series flow arrangement of two differential mobility analyzers (DMA1 and DMA2), each of which pass a narrow size range of aerosol particles depending on the voltage setting. (The device is named "nanonose" because its operation depends on nanometer-sized aerosol particles.) A successful procedure has been to set DMA1 to pass, for example, 25-nanometer (nm) diameter particles (actually a narrow size distribution centered at 25 nm), react the particles with the odor sample, heat the sample to volatilize reaction products, and set DMA2 to pass 15-nm particles. The increase in the number of 15-nm particles, produced by volatilizing reaction products from the 25-nm particles, is the raw signal that correlates with odor concentration.

From past experimental results, there is no question that the system works. It gives a response to hog odor at levels comparable to the human detection threshold. (It also responds in the same way to organic acid vapors.) Odor measurement by dilution olfactometry determines the odor-detection threshold, the odor level below which it cannot be detected by repeated measurements with a trained odor panel. The minimum requirement for the nanonose system is to determine a reproducible response to a given level of hog odor. Ideally that odor level would be the detection threshold. If we know the nanonose response for the detection threshold, determined by calibrations with olfactometry, then a sample of the synthetic mixture at an unknown concentration could be repeatedly measured and diluted until the nanonose response matches that of the threshold. The nanonose concentration of the sample could then be reported in terms of multiples of the detection threshold as is the practice in dilution olfactometry. (Likely the nanonose system would be calibrated so the odor concentration could be determined from a single measurement.) Now suppose similar measurements are made to determine the variation of the nanonose response to threshold levels of hog odor from different sources. If it can be established that variation in the detection threshold concentration found with nanonose does not vary substantially from that found by olfactometry, then the nanonose system can be regarded as a stand-alone alternative to olfactometry for measurement of hog odor. If there turns out to be considerable variation in the nanonose threshold reading for different hog odors, then the system would be less independent. This could happen, for example, if the fraction of organic acids in hog odor varies considerably among facilities. In such case the nanonose would

need to be correlated with olfactometry for each facility and periodically when sampling from that given facility.

Work Completed

• The micro model has been developed from a larger-scale air-quality model and tests on the model performance conducted. Fluent has been successfully run to show that meteorological fields of 100-m resolution can be produced from boundary conditions specified over a 10-km domain with moderate amounts of computer time. Therefore Fluent can be used to derive a detailed meteorological field for the micro model from MM5 output. Fluent simulations including inclusion of species transport also have been conducted over a more limited domain of approximately 1-km with geometric details of a specific building. For these problems also, the Fluent model also converges easily.

• The odor-measurement research effort has been focused on developing a calibration method and operating procedure for routine odor measurement. An attempt was made early on to use the system to measure odor samples taken from the HENCO farm in collaboration with an ongoing field research project where samples are collected and analyzed by olfactometry. We were unable to adequately compare results with olfactometry for co-located samples. Since that time major changes, including a re-working of the flow system, have been implemented. An improved method of generating the alkaline aerosol was introduced, resulting in more stable aerosol concentrations and the needed capability to produce much higher concentrations. Finally, a strategy of continually heating the sample inlet was found to greatly reduce the carryover between successive samples, so the instrument response quickly returns to background level following the sample response.

• Following the attempt to compare nanonose results with olfactometry using the HENCO samples, it was concluded that Tedlar bags drastically affect the odor sample. Recent results with the improved nanonose setup confirm that result. Specifically, when acetic-acid vapor is injected into a Tedlar bag containing nitrogen as carrier gas, the nanonose measurement of bag contents show little or no response. When the same procedure is followed except using a Teflon bag, the acetic-acid response is at the expected value as determined by pre-calibration with acetic-acid vapor from a glass jar. It appears that organic acids when injected into a Tedlar bag attach to the walls and are thus removed from the bag air. Likewise, a hog-odor sample collected in a Tedlar bag loses organic acids. This is consistent with HENCO measurements showing samples collected at 4 pm and analyzed at 10 pm gave much higher nanonose readings than the same samples analyzed at 10 am the following day.

• We have obtained reproducible calibration with the nanonose system using acetic acid. The response is stable and can be reproduced from day to day. Optimum settings have been determined for aerosol-generation rate, voltages of the mobility analyzers, temperatures of the heated tubes through which the particles pass, and inlet heating. A method has been developed to confidently assure that the system response is not due to water vapor and that the system measures the same odor response regardless of sample relative humidity. Hog-odor samples obtained by placing a few millimeters of slurry inside a Teflon bag give a strong response equal to the equilibrium concentration of acetic-acid vapor diluted several hundred times. Unfortunately, we did not acquire the Teflon bags until after the

olfactometry support to the SRI had ended, so we were unable to compare the nanonose instrument to olfactometry with Teflon bags.

• A persistent feature of the nanonose response is that a hog-odor mixture compared to a single acid is more complex. The final measurement procedure was to inject approximately 10 ml of an odor sample into the nanonose system, and the response forms a peak evolving in approximately 30 seconds. Acetic acid forms a well-defined single peak. A hog-odor sample forms an envelope of multiple peaks. Based on the observed behavior of the system, a plausible hypothesis is that the complex hog-odor sample experiences limited chromatographic separation, so the different acids evolve at different rates. This observation could be exploited by constructing a column to increase the chromatographic separation. Based on retention time, then, the identity of the main peaks could be identified and the system could reveal the relative amounts of the organic acids in a hog-odor sample.

Implications

• Results of simulations with the micro model for sources elevated up to 10-m show that beyond approximately 1 km from the source, elevation has little effect on ground-level odor concentration. In a case where it is desirable to reduce odor level at a mile or so from the source, it is unlikely that releasing the odor from an elevated stack would be effective. As a practical matter, an elevated source would be more effective at distances out to several hundred meters from the source.

• The problem with Tedlar bags removing organic acids from the bag was a serious hindrance in pushing the nanonose measurement technique to field application. The problem also has serious implications because of the widespread use of this method for odor quantification. Unless hog-odor samples in Tedlar bags are analyzed within a few hours after being collected, the organic-acid contribution to the odor will be greatly reduced. By mass, organic acids make up over 90 % of constituents of hog odor. The common observation that odor stays on clothes and hair after only a brief exposure to a hog barn atmosphere underlines the fact that odor attaches to surfaces. The same odor constituents that attach to clothes are likely to be the constituents that attach to Tedlar bags as molecular polarity is a key underlying property. If so, this implies that an odor sample belatedly analyzed from a Tedlar bag could be apparently deficient in commonly recognized hog-odor components, and the process of measurement of odor from Tedlar bags may drastically under represent odor concentration.

• The nanonose measurement instrument is successful from the standpoints of calibration with a laboratory standard and reproducibility of results. The method still must be compared with olfactometry, using Teflon sample bags, to establish whether it can be quantitatively correlated with olfactometry. Using off-the-shelf components, the cost of the device would approach $75 thousand. The device is much more difficult to operate than is an olfactometer. However, a single analysis can be made in 1 min after the instrument is set up. Potentially hundreds of samples could be done during a day compared to only a dozen or so with olfactometry.

Overview of Phosphorus Issues in Swine Feeding

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Phosphorus and the Environment

Phosphorus (P) is an essential element for normal growth, development, and reproduction of both plants and animals. However, excessive P levels can impair surface water quality. It is well established that P is the limiting nutrient for phytoplankton production in lakes (Vollenweider, 1968; Schindler, 1974, 1977). Although less data exist for streams and rivers, research indicates P also is a key element controlling productivity in these systems (Stockner and Shortreed, 1978; Elmwood et al., 1981; Peterson et al., 1985). High P levels in surface waters accelerates the eutrophication process and often results in the excessive production of phytoplankton such as algae and cyanobacteria. The respiration of these organisms leads to decreased oxygen levels in bottom waters and under certain circumstances (at night under calm, warm conditions), in surface waters (Correll, 1998). These decreased oxygen levels can lead to fish kills and significantly reduce aquatic organism diversity.

Excessive P levels in animal diets increases animal manure P excretion, and land application of this manure to soil can increase potential P losses from fields to surface and groundwater resources. Phosphorus loss from agricultural soils can accelerate the eutrophication of lakes and streams (Daniel 1998; Parry, 1998; Gaynor and Findlay 1995). Sharpley et al. (1994) stated, "Eutrophication restricts the use of surface waters for aesthetics, fisheries, recreation, industry, and drinking, and thus has serious local and regional economic impacts.

Much of the P reaching water is from runoff, often with sediment, from cropland receiving high rates of manure or inorganic fertilizers. While P loss to surface and ground water via P leaching through the soil profile is generally much smaller than runoff P losses, excessive P applications to soils over time will move P to lower portions of the soil profile, and this P can discharge into tile drains, ditches and eventually streams (Figure 1). Significant tile discharges of P also can occur via macropore transport of manure to tile lines after land application, especially during the dry season when cracks form in the top soil. Additionally, sandy soils with, rapid drainage and low anion exchange sites generally have greater P leaching potential than heavier textured soils.

Another impact of P on water bodies was identified in the coastal waters in the DELMARVA region in the last decade. Enrichment of the Chesapeake Basin area with nutrients including high levels of P caused an outbreak of *Pfisteria pisidia*, a dinoflagellate, which causes lesions on fish. Initially, the poultry industry was cited as the cause of the increased P levels in the water, which resulted in strict regulations forbidding land application of litter, the required use of phytase in feeds, the export of litter and the motivation to experiment with new technologies to gain other value-added resources from the litter. Later it was determined that there were probably several sources of P that contributed to pollution in the Chesapeake Bay watershed. Although an isolated case, this example highlights the potential and perceived impacts of animal manures on

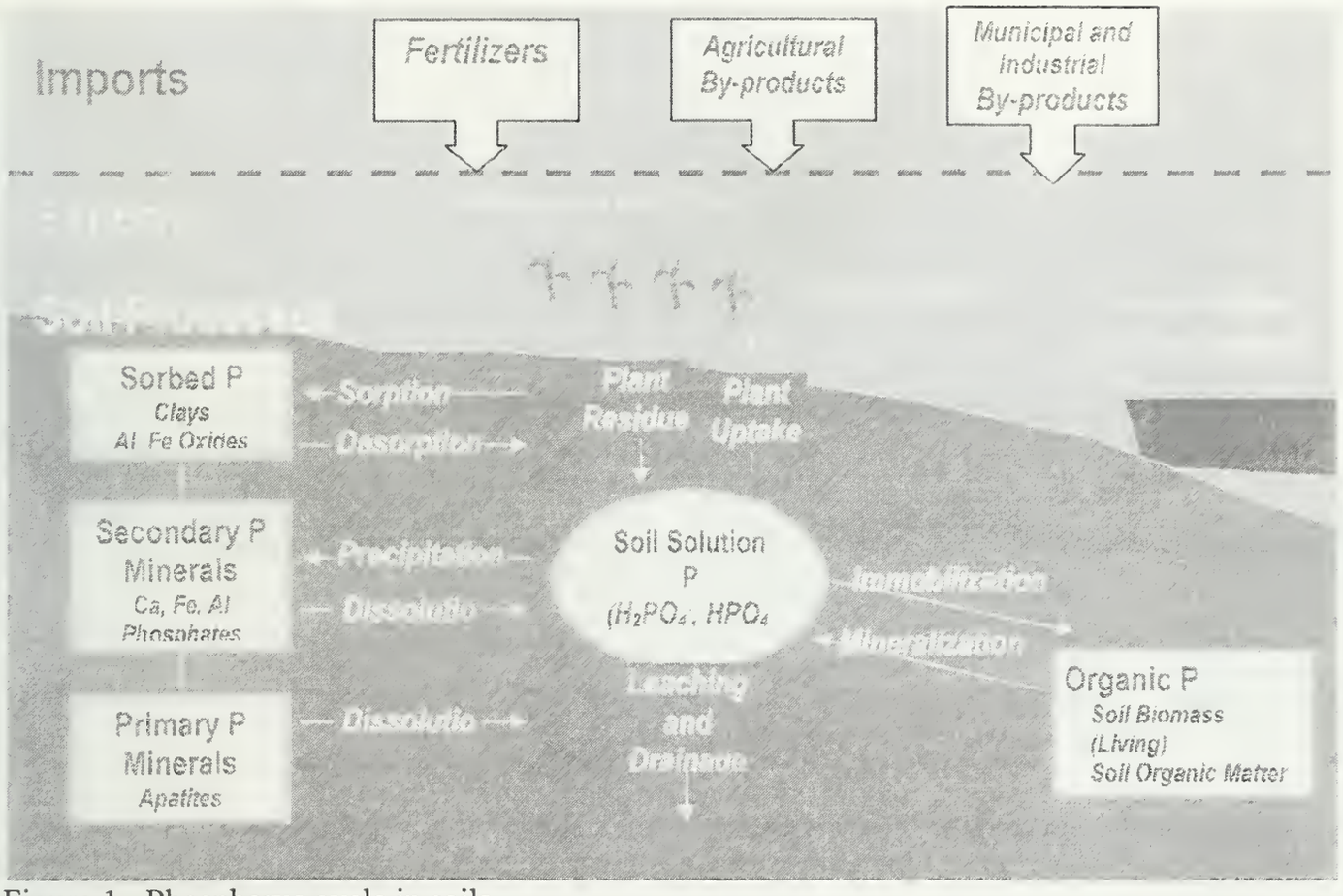

Figure 1. Phosphorus cycle in soils.

the environment, the response of regulators to an environmental situation and the changes in legislation and enforcement along with increased management, record keeping, operational requirements and costs to the producer.

The potential threat of P pollution to the waters of the United States as it relates to the livestock and poultry industries is site specific and related to the concentration of animals producing the manure relative the amount of cropland in the same region to utilize the P from the manure. In certain areas of the US, more P is produced in manure than can be utilized by adjacent productive cropland (USDA NRCS, 2000). Figure 2 illustrates specific areas in the US by county where potential excess P from manure includes concentrated swine and poultry in North Carolina, poultry in the DELMARVA area, poultry in several areas of the Deep South, beef cattle in portions of the southern Great Plains, and dairy cattle in southern California, Oregon and Washington. However, most manure P loading challenges occur at the farm or community level.

As a result of repeated applications of manure to cropland, especially at nitrogen (N) based rates, soil P levels increase, which leads to an increase in P loss potential from agricultural fields. Increased soil P accumulation at the farm and regional levels has prompted efforts to regulate manure applications on a P-basis through the recent revision the USEPA CAFO NPDES permit rule and the promotion of comprehensive nutrient management plans (CNMPs) by NRCS to control nutrient balance and flow on the livestock and poultry operations in the US.

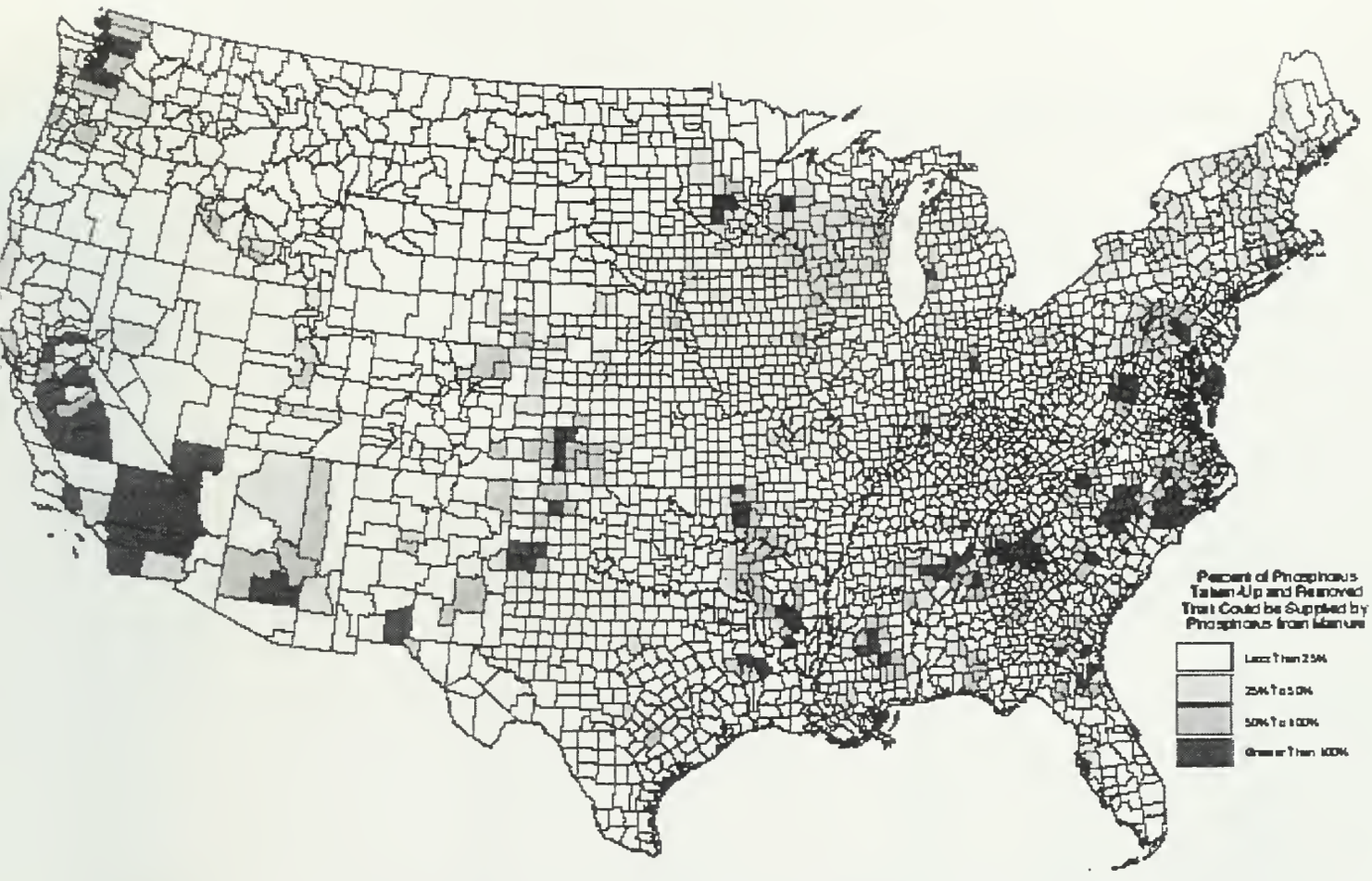

Figure 2. Percentage of phosphorus taken up and removed that could be supplied by phosphorus from manure (USDA NRCS 2000).

Clearly, excess soil P levels resulting from livestock and poultry manure applications is a nutrient distribution problem because P is deficient in some areas of the US. Of the manure that is collectable in the US, it was estimated that only about 42% of the required fertilizer P for current cropland production could be supplied by animal manure (CAST, 1996). Recent estimates (Table 1) have indicated that collectable manure P is roughly 50% of commercial P fertilizer consumption in the US (Hess et al., 2001).

The soil-water P cycle is illustrated in Figure 1. Both organic and inorganic P is present in soil, but, inorganic P is the form taken up by plants. Soil P dynamics are largely influenced by soil pH, clay content and mineralogy, amorphous iron and aluminum, and organic matter. Inorganic P is the predominant P form in both manures and commercial fertilizers. Depending on soil pH and mineralogy, inorganic P can be sorbed on the surface of clays and amorphous iron and aluminum compounds or precipitated as mineral salts until utilized by plants. Organic forms of P from crop residues, soil organic matter and manures can be mineralized by soil microorganisms and become available for plant uptake. Conversely, inorganic P can be immobilized to organic P forms not available for plant uptake. In addition, some organic P forms excreted in manure may displace sorbed inorganic and increase inorganic P runoff and/or leaching in the soil. Obviously, soil P cycling is a dynamic process.

The extent of P runoff from soils depends on rainfall intensity, soil type, topography, soil moisture content, crop cover, and the form, rate and method of P application. Surface P applications will result in more P runoff from soil than incorporated P applications (Nussbaum-

Wagler, 2003). Conservation best management practices that reduce surface runoff and erosion can greatly reduce the risk of P loss from soils.

The use of phytase in monogastric (swine and poultry) diets can significantly reduce manure P excretion, but there has been some concern about the form of P excreted in manure and eventually applied to cropland. While some studies have shown that phytase can increase manure water soluble P (WSP) in poultry litter (Moore, et al., 1998), other studies have shown reduced WSP excretion from pigs fed phytase (Hankins, 2001; Hill et al., 2003).

Table 1. Estimated quantities of manure and nutrients produced annually in the United States compared to commercial fertilizer consumption.

	Animals†	Manure‡	N‡	P_2O_5‡	K_2O‡
	millions	millions of tons§	- - - - thousands of tons§ - - - -		
Beef cattle	65	773	4,284	2,057	3,049
Milk cattle	18	364	1,825	837	1,212
Hogs	61	94	777	496	407
Broilers	1,103	36	463	282	221
Turkeys	104	13	180	154	77
Layers	419	17	234	181	107
All animals	1,770	1,297	7,763	4,007	5,073
Collectable manure¶		651	4,143	2,371	2,736
Fertilizer consumption#			11,897	4,424	5,178

† Number of animals in inventory from 1997 Census of Agriculture (USDA/NASS, 1999).
‡ Excretion values adapted from Midwest Plan Service (MWPS, 2000).
§ To convert to metric tonnes, multiply values by 0.907.
¶ Assumes 100% of manure from beef cows and dairy replacement animals (heifers and heifer calves) and 15% of manure from pigs, poultry and other cattle is *not* collected.
# Average 1990-1999 U.S. commercial fertilizer consumption (AAPFCO-TFI, 1999).

Swine Manure

Swine manure N, P and potassium (K) composition is not properly balanced for plant uptake by typical crops grown in production agriculture. The relative ratio of N, P, and K in manure from pigs fed commercial diets after storage and applied to cropland is generally 1:1:1. Corn grain production requires a 3:1:1 ratio and if corn is grown for silage, then a 2:1:2 ratio of N, P and K is desirable. Therefore, if manure is applied to meet the N requirement of corn grain production, P is over applied by 3 times crop P removal. Ideally, if the ratio of N, P and K in manure could be altered by nutritional means to meet specific crop nutrient requirements, it would alleviate a significant problem currently facing many pork producers utilizing manure as a crop nutrient resource.

Current regulations are forcing pork producers to apply manure at agronomic rates based upon the most limiting nutrient, which in most cases is P. However, there is the potential that producers can "bank" P for short periods of time if there is sufficient land available to rotate the

fields for manure application in subsequent years. A common practice may be to apply the manure to meet the N requirement of the crop, but only apply the manure to the field every 3 years. A rotation for manure application to crop fields must be established for manure applications to meet crop P needs for the crop rotation grown on specific fields.

Phosphorus in Swine Diets

Phosphorus is an essential nutrient in swine diets serving important functions as part of structural compounds in bone and in cell membranes, as a source of high energy bonds in nucleotides, as a structural component of nucleic acids, as a component of many enzyme cofactors, and as a component in many metabolic pathways (Jongbloed, 1987; Ziegler and Filer, 1996; Berner 1997). Approximately 85% of total body P is found in bone, with 14% in soft tissue and muscle, and 1% in blood (Berner, 1997). Phosphorus is stored in bone as a crystalline structure, along with Ca, known as hydroxyappetite ($Ca_{10}(PO_4)_6(OH)_2$). Deficiencies in bone P lead to rickets and osteomalacia.

Phosphorus absorption occurs throughout the small intestine with the largest portion of P absorption occurring in the jejunum (Korwaski and Schachter, 1969; Walling, 1977). There are two primary mechanisms involved in phosphate (PO_4) absorption, an active transport system and a passive transport system. Active transport of PO_4 occurs primarily in the proximal small intestine and is linearly related to lumenal Na^+ concentration (Danisi and Straub, 1980). Phosphate absorption is blocked by calcitonin (Juan et al., 1976), while $1,25(OH)_2$-D3 has a stimulatory effect (Danisi and Straub, 1980). Passive transport occurs primarily in the jejunum and ileum and is related to lumenal PO_4 concentration (Danisi and Straub, 1980). Therefore, when PO_4 intake is low, the active transport mechanism is dominant, and when the intake of PO_4 is high, the passive transport mechanism is dominant.

More research has addressed the P requirement of pigs than probably the requirement of any other mineral. However, even with this abundance of research, nutritionists still struggle to decide what the correct P level to feed is. In the past, over-formulation of P in the diet was not considered a major problem because P is relatively inexpensive to add to the diet, and performance of pigs is not hindered by small over-formulations in P, provided that Ca levels are kept at an appropriate ratio. However, with growing environmental concerns over high levels of P in swine manure, it has become necessary to minimize over-formulations in P. Producers need to minimize over-formulation of P for two reasons. First, it is simply a waste of money. Assuming, a feed to gain ratio of 2.8:1.0 for pigs up to 50 pounds, and a feed to gain ratio of 3.0:1.0 for pigs greater than 50 pounds, a producer could save approximately $0.09 per hog marketed by reducing P in the diet by 0.1 percentage-unit. Additional money would be saved due to the extra space generated in the ration by the removal of inorganic P. Second, high levels of P in swine manure are of growing environmental concern. Minimizing over-formulation is the easiest and cheapest way to reduce P excretion.

To accomplish this, the P requirement of pigs needs to be accurately defined. The most recent Swine NRC (1998) cites 151 references that in some way address P nutrition. Of these, 37 are from references in the 1990s. Of those 37, 18 are from studies investigating the effects of phytase and nine are from studies investigating the effects of porcine somatotropin on P balance.

Of the remaining 10 studies, five directly address P requirements and one addresses the bioavailability of P from different dietary sources. Therefore, recent research surrounding dietary P has focused on phytase and other dietary additives that may alter P utilization and metabolism rather than the P requirement. Even with the importance of studying new dietary additives on P utilization by swine, there is a need to question the reliability of P requirements based on data that in many cases is more than 20 years old. During that time, plant and animal genetics have changed drastically, analytical methods have changed, and the criteria for evaluating P status have changed. Thus, P requirements need to be determined for specific genetic lines at different phases of the life cycle of the pig. This would allow for more precise formulation of feeds for P in phase feeding programs and compliment the efforts of maximal N utilization that has been an emphasis in the past decade.

Availability of Phosphorus in Feeds

Historically, P requirements were reported as total P. In more recent years, it has been realized that the bioavailability of P differs among feedstuffs, and therefore we have moved to defining the P requirement on a digestible P basis. The P requirement is listed in the most recent swine NRC (1998) as the amount of P required per kilogram of diet and as the amount of P required per day. Obviously, feed intake will affect the amount of P consumed per day. Therefore, in diets with higher energy contents, it may be necessary to raise the concentration of P. Ultimately, P requirements for market animals should probably be based on the amount of P required per pound of lean tissue growth. Because of different feed intakes and lean growth potential for gilts compared to barrows, specific diet formulations are needed for gilts and barrows.

A limiting factor in the use of digestible P in diet formulations is the accuracy of P bioavailability estimates for feedstuffs. The use of apparent P digestibility as an estimator of P bioavailability in feedstuffs has been used frequently in recent studies where microbial phytase was added to the diet (Jongbloed et al., 1992; Dungelhoef et al., 1994; Mroz et al., 1994; Kornegay and Qian, 1996; Yi et al., 1996, Radcliffe and Kornegay, 1998; Robbins et al., 2000). This is supported by the conclusions of Dellaert et al., (1990) who compared eight P supplements added to supply 0.6 to 2.2 g/kg of additional P to a basal diet which contained 3.0 to 3.2 g/kg of P. In addition, a comparison of techniques used to evaluate P availability from feedstuffs was made. They concluded that apparent P digestibility was the most sensitive indicator of P bioavailability, followed by bone parameters, with blood parameters showing an insufficient response to P. However, Peo (1991) concluded that apparent Ca and P digestibility data had little value in estimating Ca and P bioavailability from feedstuffs. In the studies of Kornegay and Qian (1996) and Yi et al. (1996c) where the effects of phytase were investigated, the apparent digestibility of P did serve as a good measure of the bioavailability of P from the feedstuffs. This was further supported by the work of Radcliffe and Kornegay (1988), Skaggs (1999), and Zhang (1999).

The bioavailability of P from inorganic P sources used in swine diets is generally considered to be quite high. However, there has been a substantial amount of variation reported in the literature. Soares (1995) suggested a relative bioavailability value of 90% for defluorinated phosphate, 95% for dicalcium phosphate and 100% for monocalcium phosphate when monosodium phosphate was used as the standard and given a value of 100. A relative

bioavailability of 87% is suggested for defluorinated phosphate and a value of 100% is suggested for dicalcium phosphate when monocalcium phosphate is given a value of 100 (NRC, 1998). Kornegay and Radcliffe (1997) compared four sources of defluorinated phosphate and one source of dicalcium phosphate against a monocalcium phosphate control. They found no differences between any of the phosphate sources. The relative bioavailabilities ranged from 95.1 to 105.3%. The availability of each P source in this study can be estimated by dividing the increase (digested P in diet - basal digested P) in digested P (g/kg) when P is added by the amount of added inorganic P added and multiplying by 100. With the exception of one of the defluroinated phosphate sources (bioavailability = 58.5%) the estimated bioavailabilities of P from all sources used in the study by Kornegay and Radcliffe (1997) ranged from 71.9 to 79.3 %, with the average being 75.1%. This is in good agreement with a recent review by Kornegay et al. (1998) in which the estimated bioavailability of inorganic P across 52 experiments was 76.7% for swine.

Ultimately, diets should be formulated on an available P:available Ca basis, but there is not enough data available to allow for this at the present time. In addition, the use of enzymes such as phytase, alter the availability/digestibility of both P and Ca, which further complicates the issue. In the end, P nutrition becomes a risk management situation; with the nutritionist trying to decide how low the dietary P level can be dropped without affecting performance.

Phosphorus in Feeds

Phytate (Figure 3), the salt of phytic acid (myoinositol 1, 2, 3, 4, 5, 6 hexa, dihydrogen phosphate; IUPAC-IUB, 1975), serves as the primary storage form of P in plants, accounting for 60 to 80% of the total P in most grains. Reported values in the literature for the total P content and the phytate-P content of various plant ingredients are shown in Table 2.

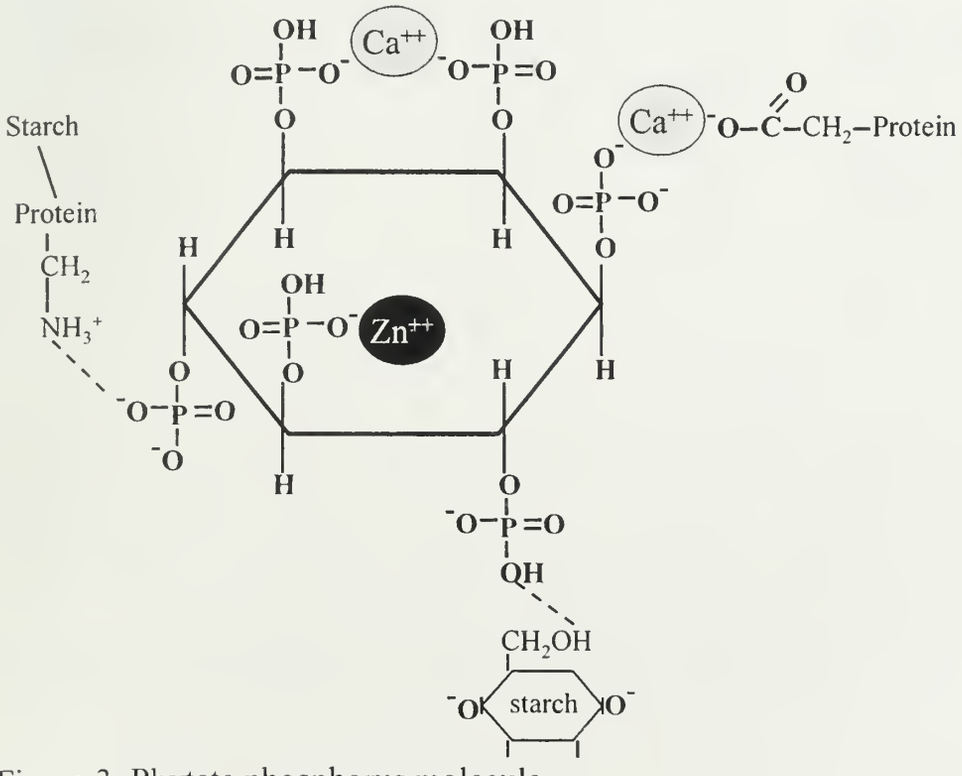

Figure 3. Phytate phosphorus molecule.

Table 2. Total and phytate P content of various feedstuffs.

Feedstuff	Total P, %	Phytate P, % of total	Reference
Corn	.28		NRC, 1998
Corn	.26	66	Nelson et al., 1968
SBM, 44%	.65		NRC, 1998
SBM, 48.5%	.69		NRC, 1998
SBM	.61	61	Nelson et al., 1968
SBM, 44%	.66	53	Eeckhout and De Paepe, 1994
SBM, 48%	.61	52	Eeckhout and De Paepe, 1994
SBM		51-61	Pointillart, 1994
Barley	.35-.36		NRC, 1998
Barley	.34	56	Nelson et al., 1968
Barley	.37	60	Eeckhout and De Paepe, 1994
Barley		51-66	Pointillart, 1994
Wheat	.35-.39		NRC, 1998
Wheat	.30	67	Nelson et al., 1968
Wheat	.33	67	Eeckhout and De Paepe, 1994
Wheat		60-77	Pointillart, 1994
Wheat middlings	.93		NRC, 1998
Wheat middlings	.80	66	Eeckhout and De Paepe, 1994
Canola meal	1.01		NRC, 1998
Canola meal	1.12	36	Eeckhout and De Paepe, 1994
Sorghum	.29		NRC, 1998
Sorghum	.27	70	Eeckhout and De Paepe, 1994
Sorghum	.31	68	Nelson et al., 1968
Meat and bone meal	4.98		NRC, 1998

Monogastric animals do not secrete phytase in sufficient quantities to breakdown the phytate molecule, hence, most of phytate P is not available for absorption. Therefore, large amounts of a highly available inorganic P source must be added to meet the P requirement of pigs. While most phytate P is not available for absorption, much of this phytate P is mineralized to inorganic P in the large intestine, and is excreted in manure as inorganic P and increase soluble P loss potential when applied to soils. Estimates of the bioavailability of P from various plant ingredients as reported in the literature are shown in Table 3.

Table 3. Estimates of P bioavailability from various feedstuffs for pigs.

Source	Bioavailability[a], %	Standard[b]	Reference
Corn	14	MSP	NRC, 1998
Corn	14	MSP	Cromwell, 1992
Corn	15		Pierce et al., 1977
Corn	12		Calvert et al., 1978
Corn	29		Pointillart, 1984
Corn	48		Pointillart, 1987
Corn	29	MSP	Huang and Alle, 1981
SBM, 44%	31	MSP	NRC, 1998
SBM, 48%	23		
SBM, 44%	31	MSP	Cromwell, 1992
SBM, 44%	27		Tonroy et al., 1973
SBM, 44%	36	MSP	Huang and Alle, 1981
Barley	30	MSP	NRC, 1998
Barley	30	MSP	Cromwell, 1992
Barley	28		Calvert et al., 1978
Wheat	50	MSP	NRC, 1998
Wheat	49	MSP	Cromwell, 1992
Wheat	46		Pointillart, 1984
Wheat	51	MSP	Huang and Allee, 1981
Wheat middlings	41	MSP	NRC, 1998
Wheat middlings	41	MSP	Cromwell, 1992
Canola meal	21	MSP	NRC, 1998
Canola meal	21	MSP	Cromwell, 1992
Sorghum	20	MSP	NRC, 1998
Sorghum	20	MSP	Cromwell, 1992
Meat and bone meal	67	MSP	Cromwell, 1992
Meat and bone meal	90	MSP	NRC, 1998

[a]Bioavailability is expressed as a percentage relative to the standard which is assumed to have a bioavailability of 100%.

[b]If no standard is listed then bioavailability is expressed as a percentage of apparent absorption

At a neutral pH phytic acid can carry one or two negatively charged oxygen atoms in each phosphate group (Erdman, 1979), giving it a total of up to 12 negative charges. Because of these negative charges, phytic acid has the ability to bind a variety of di and tri-valent cations including Ca, Mg, Zn, Cu, Fe, Co, and Cr, in the small intestine of the pig and amino acids or

peptides rendering them unavailable for absorption (Maga, 1982; Reddy et al., 1982; Morris 1986). The mineral complexing potential of phytic acid is shown in Figure 3. Phytic acid has the greatest affinity for Zn and Cu and a fairly low affinity for Ca. However, due to the much larger concentration of Ca in diets fed to pigs relative to Zn and Cu, an effect on Ca is possible. It has also been shown that the anionic phosphate groups of phytate possess the ability to bind proteins (Prattley et al., 1982) and amino acids; having its greatest affinity for the basic amino acids: lysine, arginine, and histidine (Reddy et al., 1982).

Byproduct Feeds

Byproduct feeds can serve as a source of nutrients in pig diets. Often, byproduct feeds, such as distiller's grains, corn gluten meal, wheat middlings, etc. are included in the diet if they are readily available and economically justified, especially when there is a shortage or increase in prices of conventional feed sources. Also, due the processing methods employed, nutrients in the byproducts become more biologically available and can potentially reduce nutrient excretion if the byproduct nutrients can be balanced in the diet.

Distiller's dried grains with solubles (DDGS) which contains from 0.62 to 0.87% P, have a higher concentration of available P than corn, other cereal grains, and cereal co-products, averaging 77% for DDGS compared to a range of 12 to 30% for corn, other cereal grains, and cereal co-products. Studies by Spiehs et al., (1999) showed that when formulating diets on a total P basis, the percentage of P retained tends to increase when 10 and 20% DDGS is added to grower diets compared to a control corn-soybean meal diet (63.9%, 66.3%, and 59.1%, respectively). Similar results were observed when feeding finisher diets containing up to 30% DDGS. These results suggest that the P in DDGS is more available than in the corn-soybean meal diet. Spiehs, et al. (1999) suggested that adding up to 20% DDGS to grower and finisher diets will reduce supplemental inorganic P needs in the diet, and consequently, could reduce P levels in the manure assuming that the diet is formulated on an available P basis.

The relative availability of P in corn gluten feed and wheat middlings are 59% and 41%, respectively, compared to a standard monosodium or monocalcium phosphate (NRC, 1998). In addition, byproducts from dairy processing and high protein meals from animal origin are high in available P ranging from 90 to 97%. However, there is considerable variation in total P contents of these byproduct sources that must be considered for inclusion rates in a balanced diet. An example of how processing feeds can influence the bioavailability of P is fermentation of high moisture corn (53%) compared to dry corn (12%). With the presence of bacterial derived phytase during the fermentation process more bioavailable P is released from phytic P in the corn (Cromwell, 1992).

Milling processes to degerm and dehull corn has created new interest as feed ingredient sources with reduced levels of phytic P. Initial research has shown increased digestibility of dry matter, energy and N of the degermed, dehulled corn compared to normal corn with reduced fecal dry matter and N excretion (Moeser, et al., 2002; Kendall, et al., 2003). Indigestible P was reduced by 15% with degermed, dehulled corn (Van Kempen, et al., 2003). Future processing techniques may result in feed byproducts that will allow us to precision feed pigs with highly digestible nutrients, however, economic issues may limit the implementation of these technologies.

Reducing Phosphorus Excretion

There has been a great deal of interest in lowering the level of phytate P in the diet, and thereby, making more of the plant P available to the pig for absorption. There have been two primary strategies employed to accomplish this. First, add phytase (an enzyme which breaks down phytic acid) to the diet or second, develop plants with lower amounts of phytate P. Both methods are successful as both increase P utilization, and therefore, decreased excretion. Since another paper will present information on the value of phytase in swine feeding, it will not be discussed here. Low phytic acid grains do have the potential for wide scale use in the future if crop yields can be maintained at a similar level to conventional grains. For a maximum reduction of P, a combination of low phytic acid grains and phytase may ultimately provide the producer with the greatest ability to lower dietary P levels and minimize manure P excretion.

SUMMARY

Phosphorus reaching our nations waters can adversely affect the tropic status and potential uses of the water body. If applied at excessive P rates, manure applied to cropland can increase soil P loss potential. However, the potential risk of P loss from manured fields depends upon the amount of P and chemical form of the P in the manure, method of manure application, and the soil-water conditions of the application site. Currently, only isolated areas of the US have more animal manure P generated than potential cropland P utilization.

Feed formulation and feeding programs can have a significant impact on P excretion. However, due to the lack of current research on the P requirements of today's pigs, and the availability of P in feed sources, accurate feed formulation for optimum diets is a challenge, and more specific research data are needed to reduce manure P excretion. Use of feed additives, genetically improved feed grains, and further processed feeds, if they become economically feasible, can assist in reducing P excretion.

REFERENCES

Berner, Y. N. 1997. Phosphorus. In: B. L. O'Dell and R. A. Sunde (ed.) Handbook of Nutritionally Essential Mineral Elements. p. 63. Marcell Dekker, Inc., New York.

Calvert, C. C., R. J. Besecker, M. P. Plumlee, T. R. Cline and D. M. Forsyth. 1978. Apparent digestibility of phosphorus in barley and corn for growing swine. J. Anim. Sci. 47:420-426.

CAST. 1996. Integrated animal waste management. Council for Agricultural Science and Technology Report 128. Ames, Iowa. 87 pages.

Correll, D.L. 1998. The role of phosphorus in the eutrophication of receiving waters: A review. J. Environ. Qual. 27:261-266.

Cromwell, G. L. 1992. The biological availability of phosphorus from feedstuffs. Pig News and Info. 75N-78N.

Daniel, T. C., A. N. Sharpley, and J. L. Lemunyon. 1998. Agricultural phosphorus and eutrophication: a symposium overview. J. Environ. Qual. 27:251-257.

Danisi, G. and R. W. Straub. 1980. Unidirectional influx of phosphate across the mucosal membrane of the rabbit small intestine. Pflugers Arch. 385:117-122.

Dellaert, B. M., G. F. U. Van Der Peer, A. W. Jongbloed, and S. Beers. 1990. A comparison of different techniques to assess the biological availability of feed phosphorus in pig feeding. Neth. J. Agric. Sci. 58:555-566.

Duengelhoef, M., and M. Rodehutscord. 1995. Wirkung von phytasen auf die verdaulichkeit des phosphors beim schwein (Effects of phytases on the digestibility of phosphorus in pigs). Ubers. Tierernahrg. 23:133-157.

Elmwood, J.W., J.D. Newbold, A.F. Trimble, and R.W. Stark. 1981. The limiting role of phosphorus in a woodland stream ecosystem: Effects of P enrichment on leaf decomposition and primary producers. Ecology. 62:146-158.

Erdman, J. W., Jr. 1979. Oilseed phytates: Nutritional implications. J. Am. Oil Chemists' Soc. 56:736-741.

Eeckhout, W. and M. De Paepe. 1994. Total phosphorus, phytate-phosphorus and phytase activity in plant feedstuffs. Anim. Feed Sci. Tech. 47:19-29.

Gaynor, J.D., and W.I. Findlay. 1995. Soil and phosphorus loss from conservation and conventional tillage in corn production. J. Environ. Qual. 24:734-741.

Hankins, S. L. 2001. Dietary Manipulation Effects on Nutrient Excretion and Performance of Beef Cattle and Pigs. MS thesis, Purdue University, West Lafayette, IN.

Hess, P.J., B.C. Joern, and J.A. Lory. 2001. Developing software for livestock manure and nutrient management in the USA. pp. 371-389. *In* R.F. Follet and J.L. Hatfield (ed.) Nitrogen in the Environment: Sources, Problems, and Management. Elsevier Science B.V., Amsterdam, The Netherlands.

Hill, B. E., S. L. Hankins, S. A. Trapp, A. L. Sutton and B. T. Richert. 2003. Effects of low phytic acid corn, low phytic acid soybean meal, and phytase on nutrient digestibility and excretion in growing pigs. J. Anim. Sci. 81 (Suppl. 1):37. (Abstract).

Huang, K. C. and G. L. Allee. 1981. Bioavailability of phosphorus in selected feedstuffs for young chicks and pigs. J. Anim. Sci. 53(Suppl. 1):248 (Abstract).

IUPAC-IUB. 1975. Enzyme nomenclature recommendations. Supplement I. Biochim Biophys. Acta 429:1.

Jongbloed, A. W. 1987. Phosphorus in the Feeding of Pigs: Effect of Diet on the Absorption and Retention of Phosphorus by Growing Pigs. Ph. D. Thesis, Instituut voor Veevoedingsonderzoek (I.V.V.O.), Lelystad, Netherlands.

Jongbloed, A. W., Z. Mroz, and P. A. Kemme. 1992. The effect of supplementary Aspergillus niger phytase in diets for pigs on concentration and apparent digestibility of dry matter, total phosphorus, and phytic acid in different sections of the alimentary tract. J. Anim. Sci. 70:1159-1168.

Juan, D., P. Liptak, and T. K. Gray. 1976. Absorption of inorganic phosphate in the human jejunum and its inhibition of salmon calcitonin. J. Clin. Endocrinol. Metab. 43:517-522.

Kendall, D. C., A. M. Gaines, J. W. Frank, G. L. Allee, M. Bertram and T. E. Sauber. 2003. Evaluation of dehulled, degermed corn for swine. J. Anim. Sci. Pg. 54. Midwest ASAS/ADSA meeting. (Abstract).

Kornegay, E. T. and H. Qian. 1996. Replacement of inorganic phosphorus by microbial phytase for young pigs fed on a maize-soyabean meal diet. Brit. J. Nutr. 76:563-578.

Kornegay, E. T. and J. S. Radcliffe. 1997. Relative bioavailability of phosphorus sources with different solubilities in neutral ammonium citrate (NAC) for young pigs. J. Anim. Sci. 76(Suppl 1):188 (Abstr.).

Kornegay, E. T., J. S. Radcliffe, and Z. Zhang. 1998. Influence of phytase and diet composition on phosphorus and amino acid digestibilities, and phosphorus and nitrogen excretion in swine. BASF Technical Symposium, Durhan, NC. p. 125.

Kowaski, S. and D. Schachter. 1969. Effects of vitamin D on phosphate transport and incorporation into mucosal constituents of rat intestinal mucosa. J. Biol. Chem. 244:211-217.

Maga, J. A. 1982. Phytate: its chemistry, occurrence, food interactions, nutritional significance, and methods of analysis. J. Agric. Food Chem. 30:1-9.

Moeser, A. J., I. B. Kim, E. van Heugten and T. A. T. G. Kempen. 2002. The nutritional value of degermed, dehulled corn for pigs and its impact on the gastrointestinal tract and nutrient excretion. J. Anim. Sci. 80:2629-2638.

Moore, P. A., W. E. Huff, W. F. Jaynes, G. R. Huff, J. M. Balog, N. C. Rath, T. C. Daniel, P. W. Waldroup, L. S. Davis and D. R. Edwards. 1998. Effect of high available phosphorus corn and phytase enzyme addition to broiler diets on phosphorus runoff from fescue plots. Poult. Sci. S30.

Morris, E. R. 1986. Phytate and dietary mineral bioavailability. In: E. Graf (ed.) Phytic Acid: Chemistry and Applications. p. 57. Pilatus Press, Minneapolis.

Mroz, Z., A. W. Jongbloed, and P. A. Kemme. 1994. Apparent digestibility and retention of nutrients bound to phytate complexes as influenced by microbial phytase and feeding regimen in pigs. J Anim. Sci. 72:126-132.

Nelson, T. S., J. J. McGillivray, T. R. Shieh, R. J. Wodzinski, and J. H. Ware. 1968. Effect of phytate on the calcium requirement of chicks. Poultry Sci. 47:1985-1989.

Nussbaum-Wagler, D. 2003. Phosphorus runoff from tilled soils under simulated rainfall. MS Thesis. Purdue University. West Lafayette, IN.

NRC. 1998. Nutrient Requirements of Swine (10th ed.). National Academy Press, Washington, DC.

Pallauf, J., G. Rimbach, S. Pippig, B. Schindler, D. Hohler, and E. Most. 1994. Dietary effect of phytogenic phytase and an addition of microbial phytase to a diet based on field beans, wheat, peas and barley on the utilization of phosphorus, calcium, magnesium, zinc and protein in piglets. Z. Ernahrungswiss 33:128-135.

Pallauf, V. J., D. Holer, G. Rimbach, and H. Neusser. 1992. Effect of microbial phytase supplementation to a maize-soy-diet on the apparent absorption of phosphorus and calcium in piglets. J. Anim. Physiol. a. Anim. Nutr. 67:30-40.

Parry, R. 1998. Agricultural phosphorus and water quality: a U.S. Environmental Protection Agency perspective. J. Environ. Qual. 27:258-261.

Peo, E. R. 1991. Calcium, phosphorus, and vitamin D in swine nutrition. In: E. R. Miller, D. E. Ullrey and A. J. Lewis (ed.) Swine Nutrition. p. 165. Butterworth-Heinemann, Stoneham, MA.

Peterson, B.J., A.E. Hobbie, A.E. Hershey, M.A. Lock, T.E. Ford,, J.R. Vestal, V.L. McKinly, M.A.J. Hullar, M.C. Miller, R.M. Ventullo, and G.S. Volk. 1985. Transformation of a tundra river from heterotrophy to autotrophy by addition of phosphorus. Science. (Washington D.C.) 229:1383-1386.

Pierce, A. B., C. E. Doige, J. M. Bell and D. B. Owen. 1977. Availability of phytate phosphorus to the growing pigs receiving isonitrogenous diets based on wheat or corn. Can J. Anim. Sci. 55:573-583.

Pointillart, A., A. Fourdin, and N. Fontaine. 1987. Importance of cereal phytase activity for phytate utilization by growing pigs fed diets containing tritical corn. J. Nutr. 117:907-913.

Pointillart, A., N. Fontaine, and M. Thomasset. 1984. Phytate phosphorus utilization and intestinal phosphates in pigs fed low phosphorus: wheat or corn diets. Nutr. Rep. Internat'l. 19:473-483.

Prattley, C. A., D. W. Stanley, and F. R. Van de Voort. 1982. Protein-phytate interactions in soybeans. II. Mechanisms of protein-phytate binding as affected by calcium. J. Food Biochem. 6:255-271.

Radcliffe, J. S. and E. T. Kornegay. 1998. Phosphorus Equivalency Value of Microbial Phytase in Weanling Pigs Fed a Corn-Soybean Meal Based Diet. J. Anim. Feed Sci. 7:197-211.

Reddy, N. R., S. K. Sathe, and D. K. Salunkhe. 1982. Phytates in legumes and cereals. In: C. O. Chichester, E. M. Mrak, and G. F. Stewart (ed.) Advances in Food Research. p 1. Academic Press Inc., New York.

Robbins, B. C., J. S. Radcliffe, and E. T. Kornegay. 2000. Evaluation of two commercially available phytase sources in weanling pigs fed a high phytate diet. J. Anim. Sci. 78 (Suppl. 2):5. (Abstract).

Schindler, D. W. 1977. Evolution of phosphorus limitation in lakes. Science 195:260-262.

Schindler, D.W. 1974. Eutrophication and recovery in experimental lakes: Implications for lake management. Science (Washington D.C.) 184:897-899.

Sharpley A.N., S.C. Chapra, R. Wedepohl, J.T. Sims, T.C. Daniel, and K.R. Reddy. 1994. Managing agricultural phosphorus for protection of surface waters – issues and options. J. Environ. Qual 23: (3) 437-451.

Skaggs, J. H. 1999. Efficacy and Safety of a New Gentically Modified Phytase for Improving Dietary Phosphorus Utilization of Swine and Poultry. M.S. Thesis. Virginia Polytechnic Institute and State University, Blacksburg, VA.

Soares, J. H., Jr. 1995. Calcium bioavailability. In: C. B. Ammerman, D. H. Baker, and A. J. Lewis (ed.) Bioavailability of Nutrients for Animals. p. 95. Academic Press, Inc., San Diego, CA.

Spiehs, M. J., M. H. Whitney and G. C. Shurson. 2002. Nutrient database for distiller's dried grains with solubles produced from new ethanol plants in Minnesota and South Dakota. J. Anim. Sci. 80:2639-2645.

Stockner, J.G. and K.R.S. Shortreed. 1978. Enhancement of autotrophic production by nutrient addition in a coastal rainforest stream on Vancouver Island. J. Fish Res. Board Can. 35:28-34.

Tonroy, B., M. P. Plumlee, J. H. Conrad and T. R. Cline. 1973. Apparent digestibility of the phosphorus in sorghum grain and soybean meal for growing swine. J. Anim. Sci. 36:669-673.

USDA NRCS. 2000. Manure nutrients relative to the capacity of cropland and pastureland to assimilate nutrients. Natural Resources and Conservation and Economic Research Service report NPS00-0579.

Van Kempen, T. A., E. van Heugten and A. J. Moeser. 2003. Dehulled, degermed corn as a preferred feed ingredient for pigs. 2003 North Carolina State University Swine Report.

Vollenweider, R.A. 1968. Water management research. OECD Paris. DAS/CS1/68.27. Mimeo. 183 p.

Walling, M. W. 1977. Intestinal inorganic phosphate transport. Adv. Exp. Med. Biol. 103:131-147.

Yi, Z., E. T. Kornegay, M. D. Lindemann, V. Ravindran, and J. H. Wilson. 1996. Effectiveness of Natuphos® phytase in improving the bioavailabilities of phosphorus and other nutrients in soybean meal-based semipurified diets for young pigs. J. Anim. Sci. 74:1601-1611.

Zhang, Z. 1999. Reducing Nutrient Excretion via Improved Nutrient Utilization by Supplementing Pigs and Poultry Diets with Phytase Enzyme. Ph.D. Dissertation. Virginia Polytechnic Institute and State University, Blacksburg, VA.

Ziegler, E. E. and L. J. Filer. 1996. Present Knowledge in Nutrition. ILSI Press, Washington, DC.

Efficacy of Phytase Enzymes for Releasing Phytate-Bound Phosphorus: Effects of Phytase Source, Phytase Level, and Pharmacologic Zinc Supplementation

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Previous reviews have covered our work on the efficacy of a new *E. coli*-derived phytase (expressed in yeast) for releasing phytate-bound phosphorus (P) present in corn-soybean meal diets for young pigs, growing-finishing pigs, broiler chicks and laying hens (Baker and Augspurger, 2002; Augspurger, 2003; Augspurger et al., 2003a). It is not our intent to repeat this information, but instead to present new information.

Through characterizing the P-releasing efficacy of a new *E. coli*-derived phytase, i.e., EcoPhos (ECP), our laboratory showed that the efficacy of two commercially-available fungal phytases, i.e., Natuphos (FP1) and Ronozyme (FP2), were unexpectedly low in the chick, but were higher in the young pig (Augspurger et al., 2003a). These were not the first data to show low efficacy for the fungal phytases in chicks, as Angel et al. (2001) also showed low efficacy values for FP1 in chicks. Recent work by Shirley and Edwards (2003), however, showed that supplementation of FP1 at a level of 12,000 FTU/kg resulted in almost complete digestion and release of the dietary phytate-P, which shows that FP1, at a high level, is capable of hydrolyzing phytate-P almost completely. Thus, our first objective in the work reported herein was to evaluate high levels of ECP, FP1, and FP2 in broiler chicks.

Zinc (Zn) is routinely fed at pharmacological doses (1,500 to 3,000 mg/kg) to newly weaned piglets for alleviation or prevention of diarrhea (Holm, 1988; Poulsen, 1995) and growth promotion (Hahn and Baker, 1993; Mavromichalis et al., 2000; 2001; Hill et al., 2001; Case and Carlson, 2002). Recent *in vitro* data, however, showed that Zn^{2+} was a potent inhibitor of phytase-mediated phytate-P hydrolysis, which the authors postulated was due, in part, to Zn binding causing a conformational change in the phytate moiety, thereby rendering it less accessible to phytase (Maenz et al., 1999). Zinc has been shown to form a complex with phytic acid *in vitro* that was quite stable and precipitated out of solution at Zn: phytate molar ratios of 3.5 to 4:1 (Champagne and Fisher, 1990). Additionally, it appeared that one Zn^{2+} ion may bridge two phytate molecules over time (Champagne and Fisher, 1990). Thus, our second objective in the work reported here was to ascertain whether *in vivo* pharmacologic Zn dosing of pigs would reduce the efficacy of ECP for releasing phytate-bound P.

Chick Trial (High Phytase Levels)

Data comparing 1,000, 5,000 and 10,000 FTU/kg of three different phytase products is presented in Table 1. Based on standard-curve methodology (i.e., using graded levels of iP from KH_2PO_4 as a reference standard), ECP at either 5,000 or 10,000 FTU/kg was shown to release virtually all (0.28%) of the phytate-bound P in a corn-soybean meal broiler diet. Also, in agreement with previous research in our laboratory (Augspurger et al., 2003a), ECP

released more P than an equal dose of FP1, and FP1 released more P than an equal dose of FP2.

Further details of this work are found in the paper by Augspurger and Baker (2004). Regarding the question as to whether normal or high levels of phytase will improve protein utilization, we found that neither 500 nor 10,000 FTU/kg of ECP brought about any improvement in protein utilization. This finding in chicks is in agreement with previous poultry work from our laboratory (Peter and Baker, 2001; Boling-Frankenbach et al., 2001; Snow et al., 2003) and with a recent review paper by Adeola and Sands (2003).

Pig Trial (Zinc x Phytase)

Even though there was 130 mg Zn/kg in the basal diet, some of which was undoubtedly bound to phytate (Edwards and Baker, 2000), addition of 1,500 mg Zn/kg significantly decreased ($P < 0.05$) the P-releasing efficacy of ECP phytase (Table 2). Thus, the slope value (fibula ash regressed on supplemental phytase intake) for diets containing added Zn was only 71% of the slope value for diets containing no supplemental Zn. Chick work in our laboratory has shown the same decrease in P-releasing phytase efficacy due to pharmacologic Zn supplementation (Augspurger, 2003). A growth-promoting addition of $CuSO_4 \bullet 5H_2O$ (200 mg Cu/kg), however, had no effect on phytase efficacy. It is interesting to note that (without Zn supplementation) 500 FTU/kg of ECP released 0.13% P, whereas 1,000 FTU/kg released 0.195% P from the corn and soybean meal-phytate complex. Based on the estimated quantity (0.245%) of phytate P present in the corn-soybean meal pig diet, one can estimate that 53% and 80% of the phytate-bound P was released and made available by 500 and 1,000 FTU/kg of ECP, respectively (Augspurger, 2003; Augspurger et al., 2003b)

Implications

It appears that ECP at 500 FTU/kg can replace up to 0.70% dicalcium phosphate in a pig diet not containing pharmacologic Zn supplementation. At 1,000 FTU/kg, ECP replaced 1.05% dical. In phase I and Phase II nursery diets containing 1,500 mg Zn/kg or higher, ECP replacement values for dical are reduced. Use of copper sulfate as a growth promotant, however, would not be expected to reduce the P-releasing efficacy of phytase. Economics will ultimately dictate the level of phytase products that are used in both pig and poultry diets. Nonetheless, it is important to know that virtually all of the phytate-bound P in a corn-soybean meal diet can be released and made available if high levels of efficacious phytase products are fed.

REFERENCES

Adeola, L., and J.S. Sands. 2003. Does supplemental dietary microbial phytase improve amino acid utilization? A perspective that it does not. J. Anim. Sci. 81 (E. Suppl. 2):E 78-E 85.

Angel, R., T.J. Applegate, M. Christman, and AS. Dhandu. 2001. Phosphorus sparing effect of phytase, 25-hydroxycholecalciferol and citric acid when fed to broiler chicks. Poult. Sci. 80 (Suppl 1):133 (Abstr.).

Augspurger, N.R. 2003. Efficacy of an *E. coli* Phytase for Improving Mineral Utilization in Pigs and Chickens. Ph.D. Thesis. University of Illinois, Urbana.

Augspurger, N.R., and D.H. Baker. 2004. High dietary phytase levels maximize phytate-phosphorus utilization but do not affect protein utilization in chicks fed phosphorus - or amino acid-deficient diets. J. Anim. Sci. (in press).

Augspurger, N.R., D.M. Webel, X.G. Lei, and D.H. Baker. 2003a. Efficacy of an *E. coli* phytase expressed in yeast for releasing phytate-bound phosphorus in young chicks and pigs. J. Anim. Sci. 81:474-483.

Augspurger, N.R., D.M. Webel, J.D. Spencer, and D.H. Baker. 2003b. Pharmacologic levels of zinc reduce phytase efficacy *in vivo*. J. Anim. Sci. 81 (Suppl. 1):99 (Abstr.).

Baker, D.H., and N.R. Augspurger. 2002. Means of improving phosphorus utilization in poultry and swine. Proc. Western Nutr. Conf. (Edmonton, Alberta), pp. 97-114.

Boling-Frankenbach, S.D., C.M. Peter, M.W. Douglas, J.L. Snow, C.M. Parsons, and D.H. Baker. 2001. Efficacy of phytase for increasing protein efficiency ratio (PER) values of feed ingredients. Poult. Sci. 80:1578-1584.

Case, C.L., and M.S. Carlson. 2002. Effect of feeding organic and inorganic sources of additional zinc on growth performance and zinc balance in nursery pigs. J. Anim. Sci. 80:1917-1924.

Champagne, E.T., and M.S. Fisher. 1990. Binding differences of Zn(II) and Cu(II) ions with phytate. J. Inorg. Biochem. 38:217-223.

Edwards, H.M., III., and D.H. Baker. 2000. Zinc bioavailability in soybean meal. J. Anim. Sci. 78:1017-1021.

Hahn, J. D., and D. H. Baker. 1993. Growth and plasma zinc responses of young pigs fed pharmacologic levels of zinc. J. Anim. Sci. 71:3020-3024.

Hill, G.M., D.C. Mahan, S.D. Carter, G.L. Cromwell, R.C. Ewan, R.L. Harrold, A.J. Lewis, P.S. Miller, G.C. Shurson, and T.L. Veum. 2001. Effect of pharmacological concentrations of zinc oxide with or without the inclusion of an antibacterial agent on nursery pig performance. J. Anim. Sci. 79:934-941.

Holm, A. 1988. *Escherichia coli* associated diarrhea in weaner pigs: zinc oxide added to the feed as a preventative measure. Dan. Veterinaertidsskr. 72:1118 (Abstr.).

Maenz, D.D., C.M. Engele-Schaan, R.W. Newkirk, and H.L. Classen. 1999. The effect of minerals and mineral chelators on the formation of phytase-resistant and phytase-susceptible forms of phytic acid in solution and in a slurry of canola meal. Anim. Feed Sci. Tech. 81:177-192.

Mavromichalis, I., C.M. Peter, T.M. Parr, D. Ganessunker, and D.H. Baker. 2000. Growth promoting efficacy in young pigs of two sources of zinc oxide having either a high or a low bioavailability of zinc. J. Anim. Sci. 78:2896-2902.

Mavromichalis, I., D.M. Webel, E.N. Parr, and D.H. Baker. 2001. Growth promoting efficacy of pharmacologic doses of tetrabasic zinc chloride in diets for nursery pigs. Can. J. Anim. Sci. 81:387-391.

Peter, C.M., and D.H. Baker. 2001. Microbial phytase does not improve protein-amino acid utilization in soybean meal fed to young chicks. J. Nutr. 131:1792-1797.

Poulsen, H.D. 1995. Zinc oxide for weanling piglets. Acta Agric. Scand. Sect. A Anim. Sci. 45:159-167.

Shirley, R.B., and H.M. Edwards, Jr. 2003. Graded levels of phytase past industry standards improve broiler performance. Poult. Sci. 82:671-680.

Snow, J.L., M.W. Douglas, and C.M. Parsons. 2003. Phytase effects on amino acid digestibility in molted laying hens. Poult. Sci. 82:474-477.

Table 1. Efficacy of high dietary phytase levels from three sources for improving phosphorus utilization in chicks fed phosphorus-deficient corn-soybean meal diets[a]

Diet	Weight gain, g[c,e,f,g]	Gain/feed, g/kg[c,e]	Tibia Ash	
			%[c,e,f,g]	mg[b,d,e,f,g,h]
1. Basal diet[i]	162	494	25.0	187
2. As 1 + 0.05% iP (KH_2PO_4)	222	602	28.1	252
3. As 1 + 0.10% iP (KH_2PO_4)	280	654	34.5	325
4. As 1 + 0.15% iP (KH_2PO_4)	315	667	38.9	431
5. As 1 + 0.20% iP (KH_2PO_4)	330	663	40.0	512
6. As 1 + 1,000 FTU/kg FP1	255	631	29.9	276
7. As 1 + 1,000 FTU/kg FP2	225	601	27.6	234
8. As 1 + 1,000 FTU/kg ECP	344	691	43.7	576
9. As 1 + 5,000 FTU/kg FP1	322	679	38.9	456
10. As 1 + 5,000 FTU/kg FP2	277	648	32.9	313
11. As 1 + 5,000 FTU/kg ECP	350	698	47.0	673
12. As 1 + 10,000 FTU/kg	343	684	44.2	586
FP1	315	381	37.9	415
13. As 1 + 10,000 FTU/kg	359	699	46.3	684
FP2				
14. As 1 + 10,000 FTU/kg	6	11	0.6	12
ECP				
Pooled SEM				

[a]Data are means of five pens of four male chicks fed the experimental diets during the period 8 to 22 d posthatching; average initial weight was 83 g. Phytase additions included Natuphos (FP1), Ronozyme (FP2), and EcoPhos (ECP). Data from Augspurger and Baker (2004).
[b]The linear regression of tibia ash (mg) for Diets 1 to 5 as a function of supplemental iP intake (g) was Y = 190.6 (± 8.5) + 331.3 (± 14.7) X (r^2 = 0.96).
[c]Quadratic response to supplemental iP ($P < 0.05$).
[d]Linear response to supplemental iP ($P < 0.01$).
[e]No phytase vs phytase ($P < 0.01$).
[f]ECP vs FP1 and FP2 ($P < 0.01$).
[g]FP1 vs FP2 ($P < 0.01$).
[h]ECP vs 0.20% iP ($P < 0.01$).
[i]The basal corn-soybean meal diet contained 23% CP, 0.38% P (0.10% estimated available P), 1.0% Ca, and 25 µg/kg vitamin D_3.

Table 2. Effect of high levels of zinc on phytase efficacy in young pigs fed a phosphorus-deficient corn-soybean meal diet

	Dietary supplement[a]			Weight	Fibula	Bioavail P
Diet	iP (%)	Phytase (FTU/kg)	Zn (mg/kg)	gain (g)[b,d,e]	ash (mg)[c,d,e,f,g,h]	release (%)[c,f]
1	0	0	0	248	431	-
2	0.075	0	0	334	529	-
3	0.150	0	0	425	676	-
4	0	500	0	321	603	0.130
5	0	1,000	0	375	701	0.195
6	0	0	1,500	249	406	-
7	0	500	1,500	320	564	0.092
8	0	1,000	1,500	382	616	0.124
			SEM	20	29	0.019

[a]Phytase was provided as EcoPhos, iP as KH_2PO_4, and Zn as either basic Zn chloride or Waelz-processed zinc oxide. The data were pooled across Zn sources. The basal diet contained 0.32% P (0.075% estimated available P), 0.70% Ca, 16.5 μg/kg vitamin D_3, and 130 mg Zn/kg. Data from Augspurger (2003) and Augspurger et al. (2003b).

[b]Means of 10 individually-fed pigs during a 21-d feeding period; average initial and final weights were 7.2 and 14.1 kg, respectively.

[c]Means of 5 median-weight pigs in each treatment group.

[d]Linear ($P < 0.01$) response to iP, and linear ($P < 0.01$) response to phytase.

[e]No phytase vs phytase ($P < 0.01$).

[f]No Zn vs 1,500 mg Zn/kg ($P < 0.05$).

[g]The linear regression of fibula ash (mg) for Diets 1 to 3 as a function of supplemental iP intake (g) was $Y = 430.5 \pm 16.8 + 10.2 (\pm 1.1) X$ ($r^2 = 0.87$).

[h]Multiple linear regression of fibula ash (mg) on supplemental phytase intake (FTU/d) in the absence (X_1) and presence (X_2) of 1,500 mg Zn/kg was: $Y = 424.3 (\pm 14.4) + 0.469 (\pm 0.047) X_1 + 0.332 (\pm 0.038) X_2$ ($R^2 = 0.75$). The slope of X_1 was greater than the slope of X_2 ($P < 0.05$).

Opportunities for Nutrient Recovery in Handling of Animal Residuals*

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ABSTRACT

Treatment methods are presented that can be used for nutrient recovery from animal manure and these processes are compared to the current practice. Using swine feeding operations as an example, the current practice for waste handling is that 97% of all produced waste is applied to owned or rented land after storing the waste in below-floor slurry pits or anaerobic lagoons without cover. This current practice has resulted in a significant environmental pollution. Slurry storage results in emission of odor, VOCs (mainly CH_4) and ammonia under normal operating conditions. In many cases there is not sufficient farmland for a sustainable land application without exceeding maximum nitrogen and phosphorus levels. New government regulations will encourage the treatment of animal residuals. Both aerobic and anaerobic process can be used to produce a valuable product from animal manure that can be reused. Phosphorus can be recovered by precipitation in combination with a biological phosphorus removing activated sludge system or by membrane separation in combination with anaerobic digestion.

Keywords

Phosphorus recovery, nutrient removal, activated sludge, anaerobic digestion, membrane separation

INTRODUCTION

Manure from animal feeding operations (AFOs) can be reused as a natural fertilizer and such a land application should in many cases be the preferred disposal method (USEPA, 1999). However, sustainable land application of residuals from AFOs is limited by the regional and seasonal nutrient requirements for soil enrichment and alternative methods for reuse and treatment of manure have to be considered. Often the farmlands surrounding concentrated animal production facilities are not sufficient to allow for a sustainable disposal of manure with growing AFO sizes. In the swine industry the average farm size increases as the number of farms has decreased from 330,000 to 191,000 while the total number of heads has increased slightly from 55 Mio to 57 Mio in the period from 1982 to 1992 (USEPA, 1999). Thus, a more efficient treatment of the very large mass of wastes produced by intensified animal feeding operations is required to protect soil and water recourses and to meet increasingly strict government regulations (Dentel, 2000)).

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* This chapter has previously been presented at a conference organized by the Water Environment Federation: Morgenroth, E. (2000) Opportunities for Nutrient Recovery in Handling of Animal Residuals. In Proceedings of the Animal Residuals Management Conference, Kansas City, Missouri, Nov 12 – 14; Water Environment Federation: Alexandria, Virginia. It is reprinted here with permission from the Water Environment Federation.

Agriculture has been reported as the most widespread source of pollution in the nation's surveyed rivers and lakes. In the 22 States that categorized impacts from specific types of agriculture, animal operations impact about 35,000 river miles. AFOs can pose a number of risks to water quality and public health, mainly because of the amount of animal manure and wastewater they generate. Manure and wastewater from AFOs have the potential to contribute pollutants such as oxygen-demanding substances, ammonia, nutrients (e.g., nitrogen, phosphorus), sediment, pathogens, heavy metals, hormones, and antibiotics to the environment. Excess nutrients in water can result in or contribute to eutrophication, hypoxia (i.e., low levels of dissolved oxygen) (USEPA, 1999).

Both the regulatory agencies and the public are becoming more and more concerned about the current practice of manure disposal and associated risks for environment and public health. Changes in environmental regulations for AFOs will be the result and in the future economic success or failure of the agro-industry may be determined by whether they meet today's challenge of waste handling. In certain countries in Europe (e.g., The Netherlands and Belgium) disposal of intensively produced animal wastes is beginning to be seen as a national crisis (Brett et al., 1997), particularly because of the potential to cause nutrient enrichment of surface wasters, a major contributory factor to the process of eutrophication (Greaves et al., 1999). In some countries (e.g., Netherlands) the maximum productivity of AFOs is limited by legislations on the amount of phosphorus that can be land applied (Greaves et al., 1999). Alternative sinks for nutrients and treatment technologies have to be implemented. In this paper two examples of nutrient recovery technologies are critically reviewed.

Treatment options

Treatment of manure can produce products that can easier be transported, stored, and reused and thus increase the flexibility for animal residual management. Technologies for handling manure can be classified into two basic categories (Figure 1): (1) *Contain*, where manure is stored on-site for subsequent direct land application, (2) *Convert*, where manure is treated to either degrade unwanted constituents or concentrate selected waste stream to produce valuable products for reuse. While waste treatment (conversion) may initially be more expensive compared to containment, in the long run it may be more economical as it increases the flexibility for disposal.

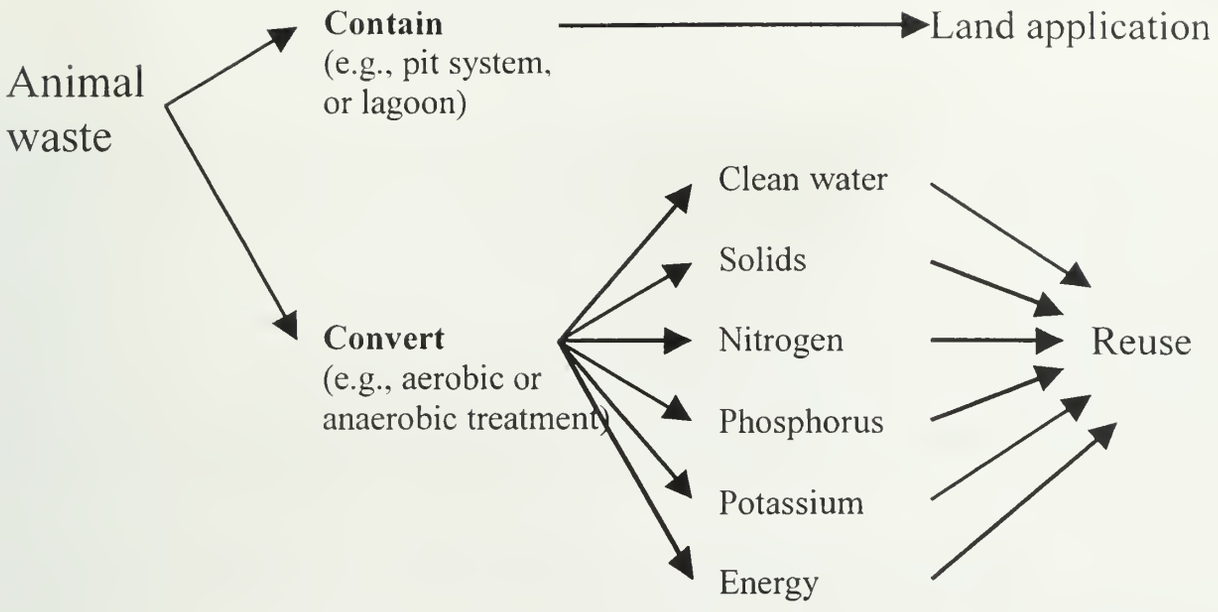

Figure 1. Conversion of manure and extraction of valuable components requires more advanced technologies than containment for subsequent land application. However, conversion of manure produces concentrated waste streams and allows for alternative pathways for reuse.

Current practice

For swine feeding operations almost all produce waste is currently applied to owned or rented land (97.3 %) (USEPA, 1999). The dominant method for storing the waste until land application is permissible depends on the size of the operation. For smaller operations (2,000 - 10,000 heads) below-floor slurry or deep pits are mainly used (70 %) whereas anaerobic lagoons without cover are mainly used for large swine operations (81 %).

Deep pits are 6 to 8 feet deep and allow for up to 6 months storage under the house. Twice a year a slurry is removed from the pit for surface application or subsurface injection or pumped to a steel aboveground storage tank or earthen storage facility. Anaerobic digestion is the primary process in anaerobic lagoon systems. Plant-available nitrogen and phosphorus in land-applied anaerobic lagoon liquid maybe at 10 % of the nutrient concentration in the flush water entering the lagoon. Much of the nitrogen in swine manure is volatilized from the anaerobic lagoon or from the spray field. Much of the phosphorus in the manure settles in the lagoon sludge and attaches to the lagoon walls and bottom. Anaerobic bacteria decompose organic matter. However, incomplete anaerobic decomposition of organics can result in offensive by-products, primarily hydrogen sulfide, ammonia, and intermediate organic acids. Thus, some conversion processes are occurring in anaerobic lagoons. However, these processes have a limited efficiency, are difficult to control, and release unwanted products into the environment (odors, methane, ammonia).

Once every 5 to 15 years, anaerobic lagoon sludge had to be removed and can be applied to land other than the spray field receiving lagoon liquid. Lagoons usually fill to capacity within 2 to 3 years of startup due to the added waste volume and rainfall that is in excess of evaporation. When the lagoon is full, water overflow will occur unless the operator is in a position to land

apply the excess waster. Thus, in the design of lagoon systems the minimum total capacity should include temporary storage for rainfall and wastewater inputs.

Uncovered anaerobic lagoons are causing environmental pollutions through emission of odors, VOCs (mainly CH_4) and ammonia under normal operating conditions. Overflows form lagoons can have detrimental effects on surface and ground water. It is very surprising that even today, very modern animal production facilities are equipped with low-tech waste handling systems. An example is a modern hog farm in North Carolina, where waste lagoons and spray irrigation were used for waste treatment resulting in a contamination of the groundwater with nitrates (USEPA, 2000). Such a contamination is associated with large remediation costs and is not acceptable with the advanced treatment technologies that are available today. As a consequence the USEPA is proposing to restrict the use of uncovered anaerobic lagoons for large AFOs and encourages more advanced treatment of animal waste (Cook, 2000).

Biological phosphorus removal combined with phosphorus recovery

A range of biological nutrient removal process based on aerobic activated sludge treatment are being used for the treatment of animal wastes, many of these us the sequencing batch reactor technology to achieve advanced nitrogen and phosphorus removal (Osada et al., 1991, Bortone et al., 1994, Maekawa et al., 1995, Tilche et al., 1999, Edgerton et al., 2000, Ra et al., 2000). The principle of biological nutrient removal is that ammonia nitrogen is removed through nitrification to nitrate and subsequent denitrification to nitrogen gas. Phosphorus is incorporated into the biomass and removed via the wasted activated sludge. To achieve enhanced biological phosphorus removal, an anaerobic zone in the activated sludge bioreactor is included providing a selective advantage for certain bacteria that accumulate phosphorus beyond that needed for biomass synthesis. Phosphorus can also be removed chemically where a precipitating agent (typically ferric chloride, alum, or other metal salts) are added at various points in the conventional wastewater treatment process train to convert soluble phosphate to particulate form. The polyphosphate is incorporated in the bacteria and is removed with the wasted activated sludge. Organic matter is oxidized during the growth of phosphorus accumulating bacteria or other heterotrophic bacteria using oxygen or nitrate as an electron acceptor.

To be able to recover phosphorus from the manure a different strategy has to be implemented that differs form the biological phosphorus removal described above. The goal is not to incorporate phosphorus into the wasted activated sludge permanently but to utilize the inherent phosphorus dynamics of phosphorus accumulating bacteria. Under anaerobic conditions phosphorus is released and can be extracted using chemical precipitation. Basic principles to recover phosphorus combined with biological phosphorus removal systems include the following removal methods (Woods et al., 1999):

- *Calcium phosphate* (Apatite) precipitation: One existing process for achieving this is the DHV Crystalactor®, a fluidized bed reactor. This technology has been implemented as a full-scale system (sidestream of an enhanced biological nutrient removal plant) at the Geestmerambacht, Netherlands, wastewater treatment facility and has been in operation since 1994.
- *Struvite* (Magnesium ammonium phosphate) precipitation: An example of this technology is the Phosnix process, an air-agitated column reactor.

- *Membrane or ion exchange technologies followed by precipitation*: An example of this technology is the RIM-NUT process using ion exchange followed by struvite precipitation.

In Figure 2 the combination of a conventional nutrient removal process with a sidestream phosphorus recovery process is shown where side stream phosphorus precipitation as struvite is achieved using the Crystalactor. van Loosdrecht et al., 1998 showed that the separate settling tank can even be avoided through modification of the main stream biological aeration tank. A quiescent zone was constructed at the end of the anaerobic reactor by construction of two baffles. Phosphorus rich water can be directly withdrawn from this in-line settler for subsequent precipitation. Sequencing batch reactors (SBR) are frequently used for wastewater treatment in rural areas. Based on the process described in Bortone et al., 1994, the SBR can be modified to allow for efficient phosphorus precipitation at the end of the anaerobic phase. A comprehensive review of phosphorus recovery methods has been prepared by Brett et al., 1997 and is summarized in Table 1.

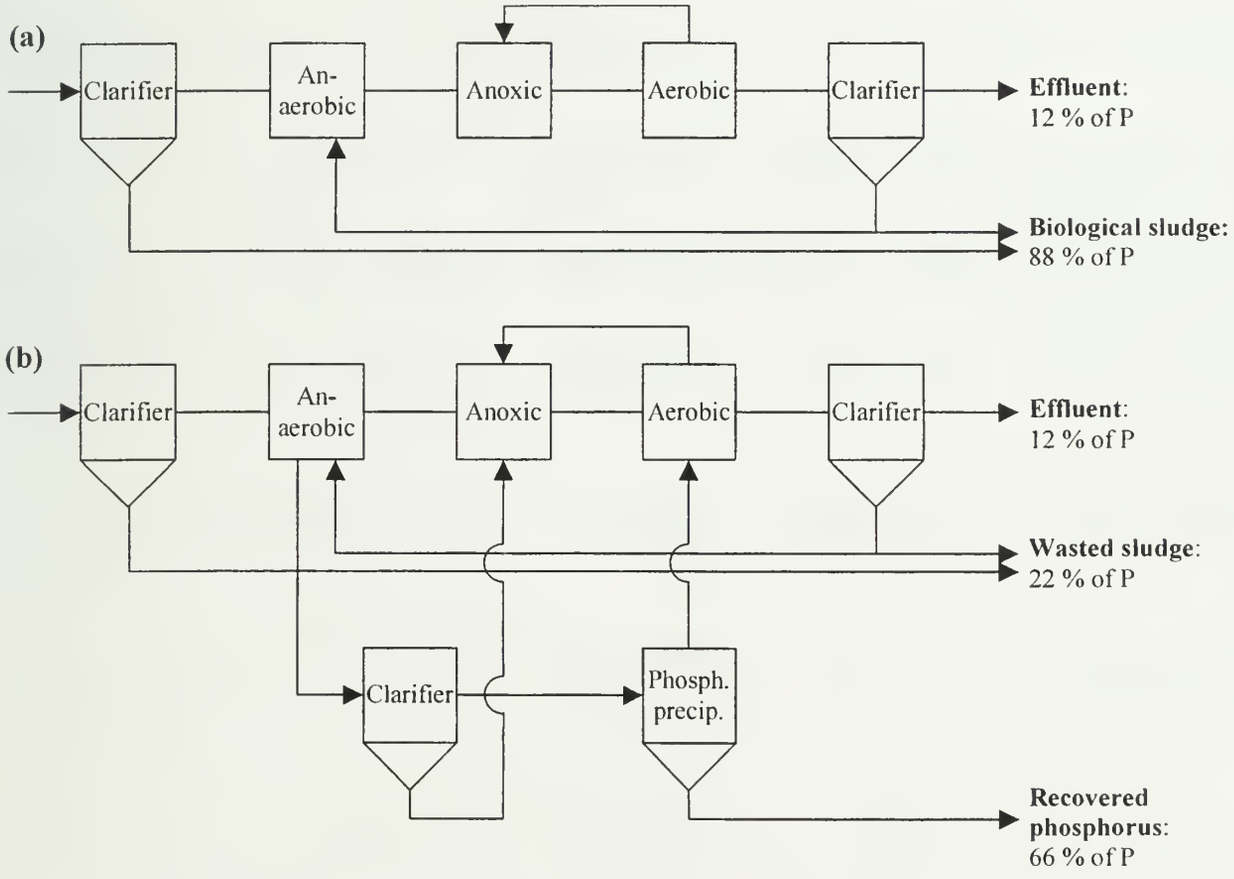

Figure 2. Process flow diagram for an EBPR process without and with sidestream phosphorus recovery: (a) A2/O process, (b) Crystalactor used for phosphorus precipitation (adapted from Woods et al., 1999 and Strickland, 1999).

An example of phosphorus recovery from animal waste via struvite precipitation is the treatment of veal calf manure performed at the Mestverwerking Gelderland Farmers Cooperative (M.G.F.C), Putten, Gelderland, The Netherlands. The veal calf manure influent has an average dry matter content of < 10% and a phosphorus content of 600 mg/l. Following biological treatment to reduce organic matter and nitrogen and to trap phosphorus in the sludge solids, struvite precipitation was carried out on the aqueous effluent which then had a phosphorus

content of approximately 200 mg/l. Struvite precipitation was induced by addition of MgO followed by continuous mixing in three stirred reaction vessels arranged in series. This procedure successfully reduced the phosphorus content of the effluent < 30 mg/l, the upper limit acceptable by the water treatment plant to which the final effluent was diverted. The described process was successful to extract phosphorus as a basis for reuse also outside of the fertilizer industry. However, at the time of the study there was not a market for the produced struvite and the recovered struvite was added to the de-watered sludge. The sludge was returned to the farms for land spreading following a six-fold reduction in volume. Phosphorus removal from the calf manure effluent prior to the struvite precipitation method had been by precipitation with lime. However, lime addition increased the sludge volume by 30 %, which increased transport costs (Greaves et al., 1999). For the described system struvite precipitation was advantageous even though the produced struvite could not be marketed separately. However, there are other examples in municipal wastewater treatment where extracted struvite was sold for US$ 150 - 200 per m^3 (CEEP, 1998).

Table 1. Application of phosphorus crystallization processes (from Brett et al., 1997, Greaves et al., 1999).

Process name	Operational status	Crystallization process	Seeding material	Recovered product
Crystalactor Pelletiser (DHV)	Fully operational	Fluidized bed	Sand / anthracite	Calcium phosphate pellets
CSIR fluidized bed crystallization column	Laboratory scale	Fluidized bed	Quartz sand	Hydroxy Apatite
Kurita fixed bed crystallization column	Fully operational	Fixed bed	Phosphate rock	Hydroxy Apatite
Organic fraction municipal waste and biological nutrient removal	Laboratory scale	Packed bed and fluidized bed	Quartz sand	Hydroxy Apatite or struvite
RIM-NUT ion exchange process	Demonstration plant	Precipitation	None	Apatite
Unitika Phosnix process	Fully operational	Spontaneous nucleation in air agitated column	None	Apatite
Sydney Water Board reactor	Pilot scale	Agitated upward flow reactor	Magnesia particles	Calcium phosphate

Anaerobic digestion

Anaerobic treatment of high strength wastewater from animal feeding operations can be advantageous because of the lower energy requirement (generally a net gain of energy) and the lower production of waste biological solids. Disadvantages of the anaerobic treatment can be the lower growth rate of microorganisms, which can mean a slower startup of the process and slow recovery after operational errors. For the anaerobic digestion of organic material different groups of organisms have to interact during hydrolysis, fermentation, and methane formation. This requires a somewhat more advanced process control compared to aerobic wastewater treatment. Another disadvantage is that anaerobic treatment processes alone are generally not suited to remove nutrients such as nitrogen or phosphorus from the wastewater.

The most common anaerobic suspended growth process is the complete mixed anaerobic digestion process. No mechanism for biomass retention is included in such a system. Thus, the hydraulic retention time is equal to the biomass retention time within the reactor. Large reactors with long hydraulic retention times are required to retain slow growing anaerobic bacteria within the reactor.

One way to reduce the size of the anaerobic reactor is to actively retain solids. Ross et al., 1992, combined anaerobic digestion with an ultrafiltration membrane separation that allows passage of treated liquid, but retains the solids within the reactor. This process was called ADUF (Anaerobic Digestion UltraFiltration). The membrane bioreactor offers three major advantages that stem from the fact that the membrane is a perfect separator for solids. First, the membrane eliminates the possibility of uncontrolled biomass loss to the effluent and, therefore, a sudden washout of slow-growing anaerobic bacteria. Second, effluent quality is improved, since it contains not suspended organic matter. Third, the volumetric loading can be increased to very high levels, since loss of biomass is impossible. The main disadvantage of the membrane bioreactor is added costs: capital costs to install the membrane, energy costs to pump the water to and through the membrane, and replacement or cleaning costs to overcome membrane fouling (Rittmann and McCarty, 2000). Ross et al., 1992 successfully applied the ADUF process for the treatment of maize-processing effluent.

An integrated system for the treatment of swine wastes was developed on the basis of the ADUF process, where the anaerobic digestion with ultrafiltration for biomass retention is combined with downstream processing using ammonia stripping and reverse osmosis. Such a process, termed BIOREK (Bioscan, AS, Denmark), has recently been developed to full-scale for the treatment of pig manure in Denmark treating 40 m^3/d of liquid manure (1,100 sows, Sandager Skovgaard) (Norddahl and Rohold, 1998). The basic schematic of the BIOREK process is shown in Figure 3. Swine manure slurry is filtered using a rotating sieve with a 1 mm hole size to remove coarse material. Permeate from the filter is collected in a pre-storage tank from where it is fed into the anaerobic digestion unit. The hydraulic retention time in the mesophilic digester is six days. The solids retention time in the digester is controlled by sludge wasting. The ultrafiltration unit has a mean molecular weight cut-off of 40,000 Da, which means that macromolecules and bacteria are retained in the digester. More than 80% of the total solids in the permeate is inorganic compounds. Permeate from the ultrafilter is led to an ammonia stripper in which more than 95 % of the ammonia and carbon dioxide dissolved in the permeate is separated into a liquid as an ammonia hydro-carbonate salt with a concentration of 10 - 15%. Removal of ammonia produces

a concentrated product that can be used for controlled fertilization and stripping is also required to reduce membrane fouling of the reverse osmosis unit. Effluent from the stripper contains the remaining salts, mainly potassium and phosphate, is treated using reverse osmosis. Products from the reverse osmosis are a phosphate and potassium rich concentrate and clean water that is sterile, without particles, and with a low organic and low salt concentration. The reverse osmosis process is operated at 32 bar and a temperature ranging from 35 to 40°C. Biogas generated in the anaerobic digester has to be treated because of high concentrations of H_2S. Desulfurication is carried out biologically by adding air to the biogas and using oxygen as an electron acceptor. Sulfur is produced that is removed as a sulfur slurry. Generated biogas is then used to generate energy and excess heat is used to heat the anaerobic digester.

The described BIOREK converts pig manure to concentrated products that can be stored locally and reused as fertilizers. Concentrated nutrients can be transported longer distances and they can be used for purposes outside of the fertilizer industry (other chemical industries). Sterile and particle free water can be reused within the AFO or for irrigation.

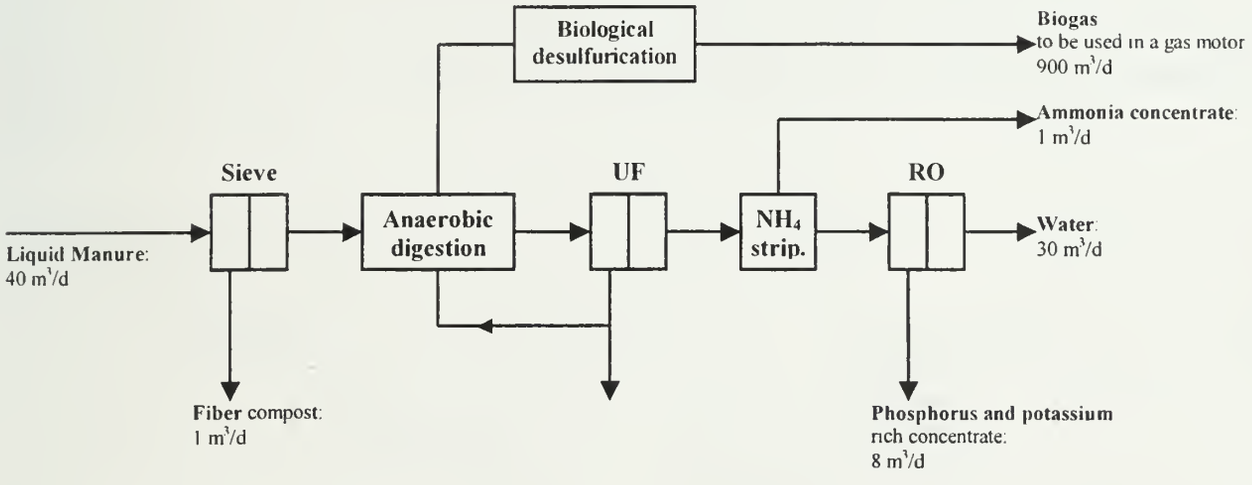

Figure 3. Overall mass balance for the Biorek process. (Sieve: removal of particles > 1mm, UF = Ultrafiltration (40 kDa), RO = Reverse Osmosis)

Process selection

A whole spectrum of technologies for the treatment of animal residuals is available. We have the technology to treat animal manure to whatever degree of purity we want - at a price (Harremoës, 1998). But how do we select for the appropriate level of treatment? Engineers can help to select a process for a specific application by evaluating pros and cons for different treatment technologies, by cost-benefit analysis, and maybe by making improvements to existing technology. However, process selection should be considered in a much broader context (Figure 4). Society has to agree on accepted levels of pollution and also then on the willingness to pay to reach this level. The establishment of effluent requirements and regulations for design and operation of treatment facilities is one way of setting these acceptable levels of pollution. In the US the public is becoming more concerned about agriculture related pollution, which is reflected in by more stringent requirements currently proposed by the USEPA (Cook, 2000).

In agriculture the recourses that can be devoted to environmental protection are quite limited. With a low profit margin new treatment technologies cannot be implemented without increasing the price of the end product. Farmers are fighting against new and stricter regulations that will be implemented in the near future (Cook, 2000). It may be interesting to compare this situation with the increased requirements for the treatment of municipal wastewater over the last 30 years. Stricter regulations have caused the cost for water to increase by a factor of five (numbers are for Denmark). This increase has been the most effective way of making industries save water, switch to cleaner production or purify in house before discharge. The attitude of industry has change from hostile opposition to investments in pollution abatement during the 70'es, over reluctant allocation of funds in the 80'es to making environmental issues a question of public image in the 90'es (Harremoës, 1998).

New technological developments are occurring that will facilitate the implementation of technologies for the treatment of animal residuals. Modular systems are being developed that can be produced at an industrial level at lower costs. The combination of reliable sensors with improved process understanding has made it possible to improve process performance on the basis of on-line sensors and continuous optimization of operation (Harremoës, 1998). Decentralized treatment units at the farm level can be operated remotely using online control to relieve farms from the burden of having to devote their efforts to learn how to operate new and advanced technologies.

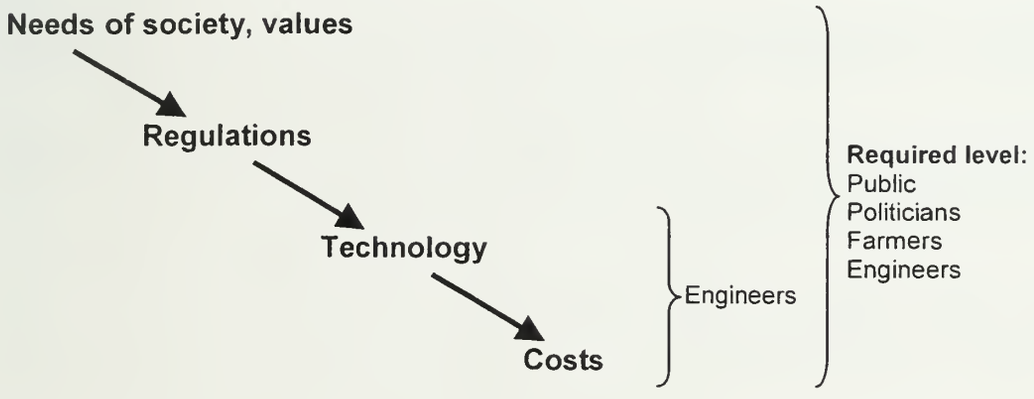

Figure 4. Process selection should be determined by agreeing on an acceptable level of pollution and a willingness to pay for required standard.

CONCLUSIONS

- Current practice of on-site storage and direct land application is not sustainable for large animal feed operations.
- New treatment technologies are required to either treat animal waste so that effluents can be discharged to the environment. Nutrients extract that can be safely stored, economically transported for a controlled land application, or even reused outside of the fertilizer industry.
- Treatment technologies such as aerobic wastewater treatment combined with phosphorus recovery or anaerobic treatment combined with membrane separation can be used for nutrient recovery.
- Small-scale modular treatment systems are required that can be mass-produced using modern industrial methods to provide a reliable, effective and reasonably priced treatment

technology. Remote control and operation technologies have become feasible today that can relieve the local farmer from having to operate new and advanced technologies.

REFERENCES

Bortone,G., Malaspina,F., Stante,L. and Tilche,A. (1994): Biological Nitrogen and Phosphorus Removal in an Anaerobic/Anoxic Sequencing Batch Reactor with Separated Biofilm Nitrification. *Wat.Sci.Tech.*, **30**, (6), 303-313.

Brett,S., Guy,J., Morse,G.K. and Lester,J.N. (1997): *Phosphorus removal and recovery technologies*. Selper Ltd., London.

CEEP (1998): Recovery of phosphates for recycling from sewage and animal wastes. In: Centre European d'Etudes des Polyphosphates (CEEP), conference at Warwick University, UK, 6.-7. May.

Cook,M. (2000): Water quality impacts, concerns and permitting animal residuals. In: Animal Residuals Management 2000 organized by the Water Environment Federation, Kansas City, Missouri, November 12-14, 2000.

Dentel,S.K. (2000): Future Trends, Research Needs, in Environmental Processes. *J.Envir.Engr.*, **126**, (8), 685-686.

Edgerton,B.D., McNevin,D., Wong,C.H., Menoud,P., Barford,J.P. and Mitchell,C.A. (2000): Strategies for dealing with piggery effluent in Australia: the sequencing batch reactor as a solution. *Water Science and Technology*, **41**, (1), 123-126.

Greaves,J., Hobbs,P., Chadwick,D. and Haygarth,P. (1999): Prospects for the recovery of phosphorus from animal manures: A review. *Environmental Technology*, **20**, (7), 697-708.

Harremoës,P. (1998): Upgrading our inhibited urban water systems. *Water Science and Technology*, **37**, (9), 1-8.

Maekawa,T., Liao,C.M. and Feng,X.D. (1995): Nitrogen and Phosphorus Removal for Swine Waste-Water Using Intermittent Aeration Batch Reactor Followed by Ammonium Crystallization Process. *Water Research*, **29**, (12), 2643-2650.

Norddahl,B. and Rohold,L. (1998): BIOREK principle. In: Bioenergy '98, Madison, USA, October.

Osada,T., HAGA,K. and Harada,Y. (1991): Removal of nitrogen and phosphorus from swine waste-water by the activated-sludge units with the intermittent aeration process. *Water Research*, **25**, (11), 1377-1388.

Ra,C.S., Lo,K.V., Shin,J.S., Oh,J.S. and Hong,B.J. (2000): Biological nutrient removal with an internal organic carbon source in piggery wastewater treatment. *Water Research*, **34**, (3), 965-973.

Rittmann,B.E. and McCarty,P.L. (2000): *Environmental Biotechnology: Principles and Applications*. McGraw-Hill, New York . ISBN: 0072345535.

Ross,W.R., BARNARD,J.P., STROHWALD,N.K.H., GROBLER,C.J. and SANETRA,J. (1992): Practical application of the ADUF process to the full-scale treatment of a maize-processing effluent. *Water Science and Technology*, **25**, (10), 27-39.

Strickland,J. (1999): Perspectives for phosphorus recovery offered by enhanced biological P removal. *Environmental Technology*, **20**, (7), 721-725.

Tilche,A., Bacilieri,E., Bortone,G., Malaspina,F., Piccinini,S. and Stante,L. (1999): Biological phosphorus and nitrogen removal in a full scale sequencing batch reactor treating piggery wastewater. *Water Science and Technology*, **40**, (1), 199-206.

USEPA (1999): Preliminary Data Summary: Feedlots Point Source Category Study, EPA-821-R-99-002, January 1999.

USEPA (2000): North carolina hog farm agrees to comply with emergency administrative order issued by the EPA. EPA Environmental News.

van Loosdrecht,M.C.M., Brandse,F.A. and de Vries,A.C. (1998): Upgrading of waste water treatment processes for integrated nutrient removal - The BCFS (R) process. *Water Science and Technology*, **37**, (9), 209-217.

Woods,N.C., Sock,S.M. and Daigger,G.T. (1999): Phosphorus recovery technology modeling and feasibility evaluation for municipal wastewater treatment plants. *Environmental Technology*, **20**, (7), 663-679.

Variable Rate Manure Spreader: Technology to Validate a Nutrient Management Plan

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INTRODUCTION

Better accounting of manure nutrients helps save commercial fertilizer costs and helps establish the value of manure assigned to neighboring crop farmers. Federal and state regulations require reporting of manure applications to cropland, and imply that calibration of equipment must be carried out to some (unspecified) level of accuracy. Furthermore, there are areas within many fields where application of manure is not allowed at all; automatic shutoff of equipment when entering those setback areas is needed. Most liquid slurry tank spreaders have a simple gate valve on the discharge pipe to the applicator, and the gate valve is opened fully while spreading manure in the field. Those spreaders do not have any method for varying the flow rate of manure coming out of the tank; therefore the only way to change the application rate per acre is to vary the ground speed of the vehicle. Historically a nitrogen based application rate could usually be accommodated with the ground speed variation method. But since the ratio of nitrogen to phosphorus in manure is usually out of balance with respect to crop needs, the phosphorus content in the manure often being two to four times the crop uptake when manure is applied based on nitrogen needs, producers are forced by regulation to reduce application rates to keep from over-supplying phosphorus. Unregulated applicators often cannot be pulled at high enough ground speeds to accomplish the low phosphorus based rates required by manure nutrient management plans. Factors that make it undesirable or impossible to increase the field travel speed enough to reduce the application rate include: the draft requirement is too high for the tractor; the soil injection toolbar causes undesirable tillage pattern (too much soil thrown for the intended operation); the vehicle dynamic characteristics and condition of the field make it impossible to maintain control or are hazardous to equipment and the operator. The only suitable way to get acceptable application rates in these cases is to reduce the flow leaving the tanker through a controlling mechanism. Being able to set any constant rate of slurry flow, over a fairly wide range from full flow to perhaps one-fourth of the maximum, is the **first level of automation**.

A further advantage to having variable rate flow control is allowing for ground speed changes as the vehicle travels through the field. Many fields have varying implement draft requirements caused by changing slopes, different soil types, wet spots, etc. The vehicle must be slowed approaching turns and to go around obstacles. Having a mechanism to sense ground speed and

reduce manure flow rate accordingly, thus keeping a constant per-acre application rate, is the **second level of automation.**

Fields which vary in their productivity, soil types, and other characteristics that determine the crop nutrient needs should have the manure application rate matched to those needs as the slurry delivery vehicle traverses the field. To accomplish that level of field nutrient management, a GPS/GIS (global positioning system/geographic information system) interface system such as that used by other precision agriculture technologies (grid based soil testing, automated yield mapping and variable rate fertilizer application) can be adapted to the slurry spreader (Morris et al. 1999). This constitutes the **third level of automation.**

Finally, since manure slurry is not a consistent product in its nutrient content or its fluid properties, on-board sensing of the product as it leaves the slurry tank discharge – the **fourth level of automation** – is needed to provide the "fine adjustment" on manure application rates throughout the field.

The advantages of a fully developed variable rate slurry spreader technology cannot be overemphasized. Such systems will reduce time spent in field calibration, will give much more accurate results with as-applied verification, will reduce commercial fertilizer inputs, and will provide a higher level of accountability in implementing state- and federally-mandated nutrient management plans. Having the ability to incorporate field-specific mapping through GPS/GIS will enable valuable integration of the manure nutrient management plan into the rest of the farm's agronomic operations. Integrated GPS coupled mapping will also provide automatic shutting off of application equipment within setback areas (near streams, wells, tile inlets, and other sensitive areas.)

SYSTEMS CURRENTLY AVAILABLE

At least three North American manufacturers of slurry tankers offer options for variable rate manure spreading. Two use on-board centrifugal pumps to discharge the manure from the tanks to the toolbar applicators. The third uses a positive displacement pump. In all cases the liquid flow rate sensing and feedback systems incorporate magnetic flow meters, and the systems change pump or valve settings in response to

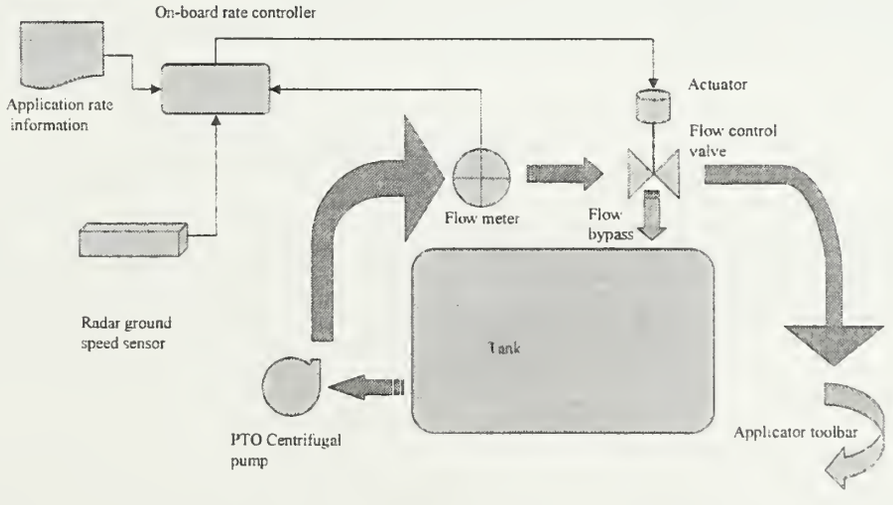

Figure 1. Slurry tanker with PTO pump and variable rate application mechanism. Not shown: tank fill port. Tank headspace is not sealed.

the flow rate requested by on-board computers and ground speed sensors. The applicators include GPS/GIS rate control systems (Figure 1.)

NOT AVAILABLE: VARIABLE RATE VACUUM LOADED TANKERS AND ON-BOARD NUTRIENT SENSING

In many ways the vacuum loaded and pressure discharge tanker is the most flexible vehicle for loading and delivering manure from the farm to the field. However, there is currently no manufacturer of hardware that supplies a variable rate application system for vacuum loaded tankers.

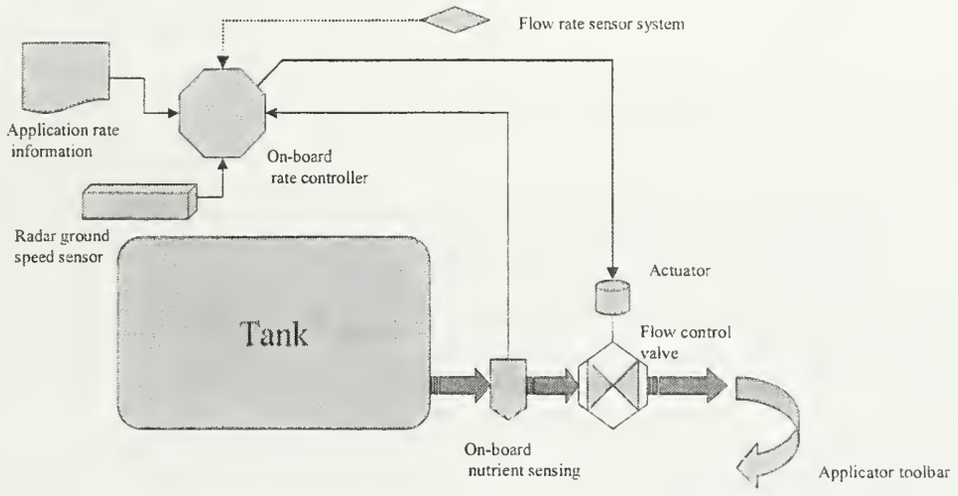

Figure 2. Variable rate slurry tank with on-board nutrient sensing. Not shown: slurry pumping or tank loading systems.

Compared to manure, commercial fertilizer has the advantage of being a homogeneous material, i.e. its nutrient concentration doesn't change over time or throughout the load. Manure can of course vary in nutrients and in solids content from load to load and even within an individual load. The need for an on-the-go nutrients sensor, at least for nitrogen and phosphorus, is immense. However, responses of simple transducers – e.g. electrical conductivity, pH, and near-infrared reflectance – have not shown good correlation with manure nutrient concentrations. Some new on-board test is needed (Figure 2.)

PROJECT OBJECTIVES

The objectives of this project were to (1) develop a reliable, low-cost prototype variable rate slurry application rate control system for a vacuum loaded tanker, and (2) develop a rational strategy for determining the expected accuracy of a variable rate manure delivery system. The results of the second objective were reported in Funk et al. (2003).

METHOD

The method included building the prototype, and laboratory- and field-testing it. The earlier prototype work was reported in detail in Funk et al. (2000, 2002). A commercially available vacuum slurry tank was fitted with a pinch valve and pneumatic pressure sensing array, and two different slurry delivery devices: a broadcast device with orifice and splash plate, and a soil injection toolbar. The slurry tank used was a twin-axle unit (Better-Bilt™ Model 2600VT, Top

Air Incorporated, Cedar Falls, IA) with rear discharge and a PTO-operated vacuum/pressure air pump capable of maintaining approximately one atmosphere of pressure on the tank during discharge of the tank's contents. A pressure relief valve on the tank prevented over-pressurizing the vessel. The rear mounted six-inch discharge was fitted with a hydraulically operated gate valve, which was fully open during testing.

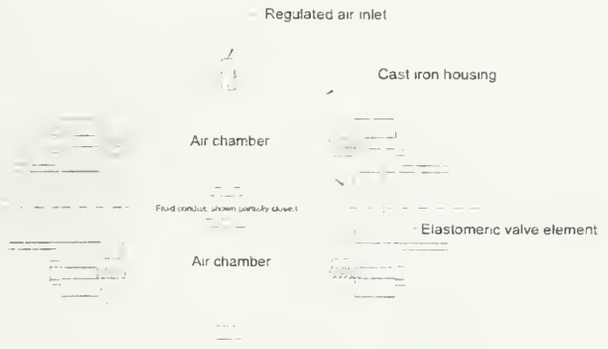

Figure 3. Pneumatic pinch valve cross section.

The pneumatic pinch valve has become a common element in wastewater treatment systems because of the valve's inherent non-clogging construction (Fig. 3) and its ease of connection to automatic controls. In this project a pneumatic pinch valve was interposed between the slurry tank discharge and the slurry application device (the broadcast device for one set of tests, and the soil injection toolbar for another set.) The pinch valve served both as a flow metering and flow measuring device, the valve serving as a variable-area obstruction flow meter.

Three different pinch valves were tested: a four-inch Red Valve™ (Red Valve Company, Inc. Pittsburgh, PA) Type A, a four-inch Elasto-Valve™ type AJ-AL (Elasto-Valve Rubber Products Inc., Sudbury, ON), and a six-inch Red Valve™ Type A. The smaller diameter valves were useful in early tests because of their smaller bulk, and were evaluated to see how their flow characteristics compared. Only the six-inch valve was field tested.

The tank was supplied with a quick-coupled broadcast device consisting of a 90-degree sweep elbow and detachable orifice with a splash plate. The 4-inch sweep elbow was reduced from the nominal discharge diameter by a series of two pipe reducers in a welded assembly. Orifice diameter was 2 inches. Flow tests were conducted both with the orifice in place and removed. A five-shank soil injection toolbar (Top Air™) was supplied that was attached to the slurry tank for the field tests (Fig. 4 and 5).

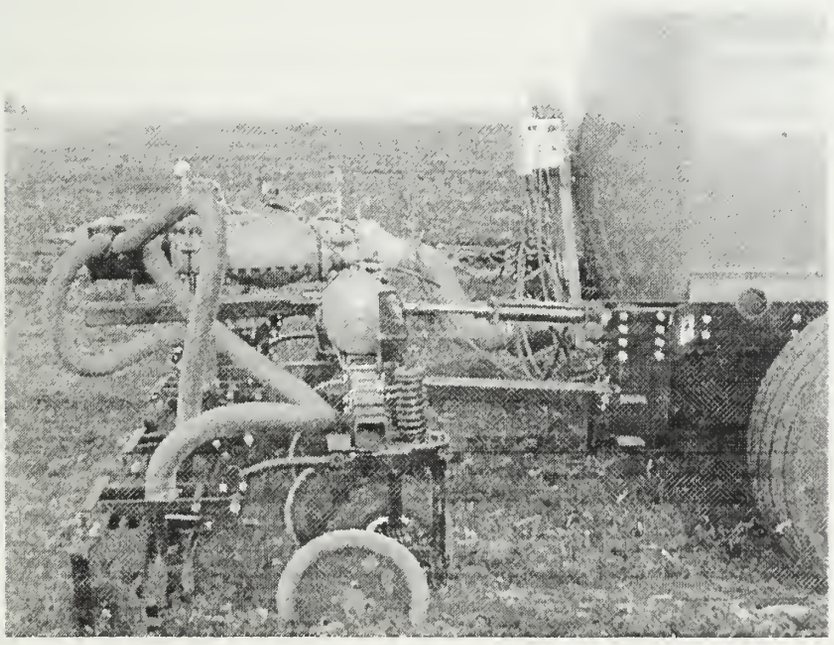

Figure 4. Field tests of the slurry tank showing pinch valve (left center), air tank (over toolbar) and controller box (on tank).

Flow rates in the first prototype development stage were obtained by time-based weight changes of the total slurry tank system, as measured by an interconnected set of five portable electronic

wheel scales (Model PT300™, Intercomp, Minneapolis, MN). The slurry tank and scales served as a portable "hydraulics table." Later a set of datalogger-compatible axle and tongue load scales was installed on the tanker to improve the high-flow-range stationary calibration tests.

Using clear water as the fluid, flow rates out of the tank and pressures were measured to characterize the pinch valve and produce a prediction function. Following field tests with lagoon liquid (less than 1% solids) and dairy slurry (about 2% solids), further calibration tests were run, also using the lagoon liquid and dairy slurry.

Since the pinch valve required regulated air pressure for its flow-control activation, a low-cost, reliable pressure sensing circuit connected to the same air supply was developed. A 12 VDC air compressor (Thomas model # 405ADC38/12) was used for field tests and later calibrations. To measure liquid differential pressure across the pinch valve being tested, a pneumatic air bleed arrangement was built which incorporated inexpensive differential pressure transducers (Omega Engineering™ model PX 137-030, 0-90 mV at 0-30 psi, 12 VDC excitation) on the pneumatic supply lines (Fig. 6).

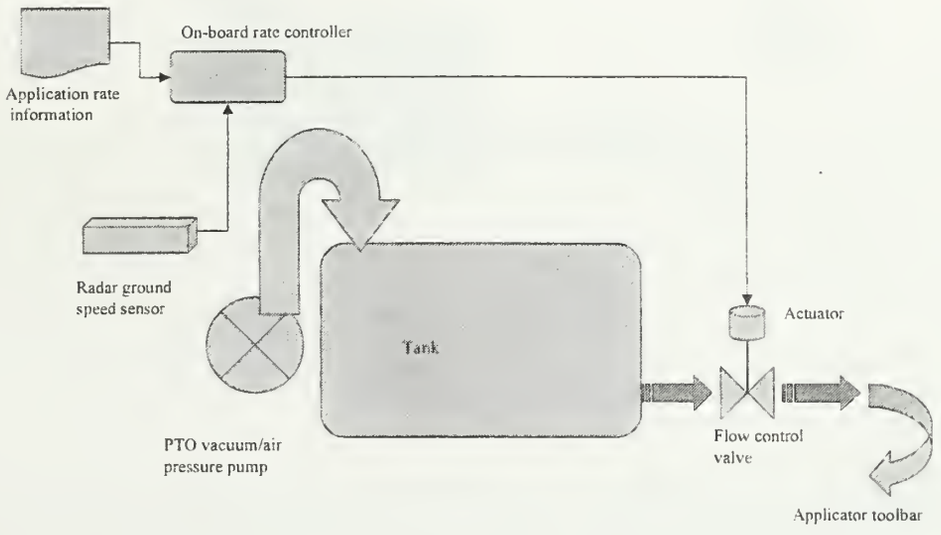

Figure 5. Slurry tanker with vacuum loading/pressure discharge and variable rate application mechanism, with no flow rate feedback. Not shown: tank fill port. Headspace is sealed, and pressurized in the field by the PTO pump.

Liquid pressures on either side of the pinch valve were measured as the air pressure in the supply lines between the 0.020 inch stainless steel restrictor orifices and the liquid main conduit from the slurry tank. Bourdon-tube pressure gauges were used for data validation. A second sensor measured the pressure difference between the tank headspace and the liquid inlet to the pinch valve; and a third sensor measured the pressure difference between the pinch valve outlet and the atmosphere, which represented the final pressure drop across the injection toolbar. To obtain the ground speed related flow control in field tests, a radar gun (Dickey-john™) was installed on the tanker and the output connected to the data logger, a linear approximation being programmed in. The tanker was field tested and various hardware refinements were made to improve reliability. A top view of the control system is shown in Figure 7.

RESULTS

Tests with the broadcast equipment showed that the low to medium flow rates were stable and predictable (Fig. 8). High flow rates where the pinch valve was open or almost completely open were harder to predict by the pinch valve case pressure only, but the "total pressure" was a good indicator of that range of operation (Fig. 9). Stationary calibration tests with the soil injection equipment (Fig. 10) also showed moderately good flow control in the low- to mid-range flow rates. Observations in the field indicated that the radar ground speed sensor provided continuous input to the datalogger/controller and varied the slurry application rate according to ground speed.

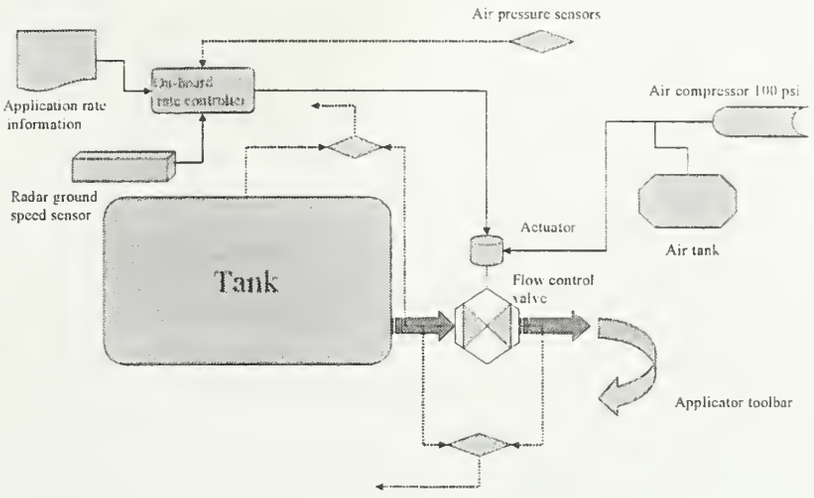

Figure 6. Vacuum loaded slurry tank with air pressure sensing feedback control. Sensors predict slurry flow by measuring air line bleed pressure into the slurry stream, and tank headspace pressure. Not shown: high pressure air bleed supply line and step-down orifices.

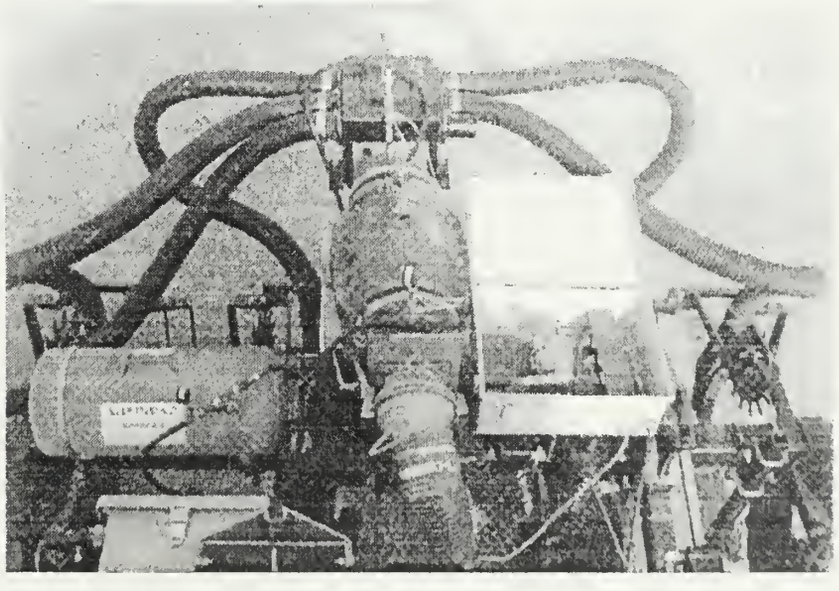

Figure 7. Top rear-facing view of variable rate control system installed on injection toolbar of vacuum loaded slurry tank. Center, pneumatic pinch valve. Top center, slurry distribution manifold. Right, 12 VDC pump and pressure sensors. Bottom left, I/P transducer housing. Left, air tank.

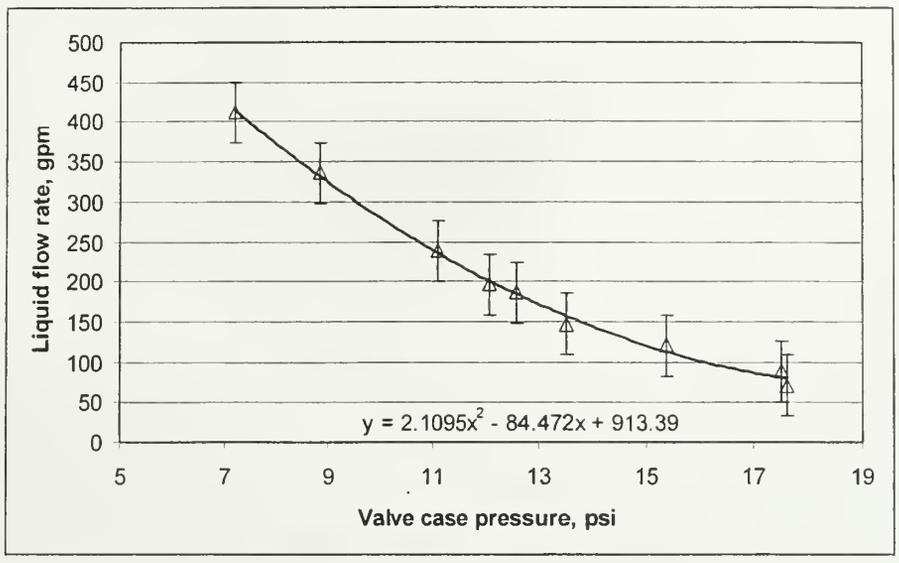

Figure 8. Slurry tank flow v. 6" valve case pressure for broadcast device.

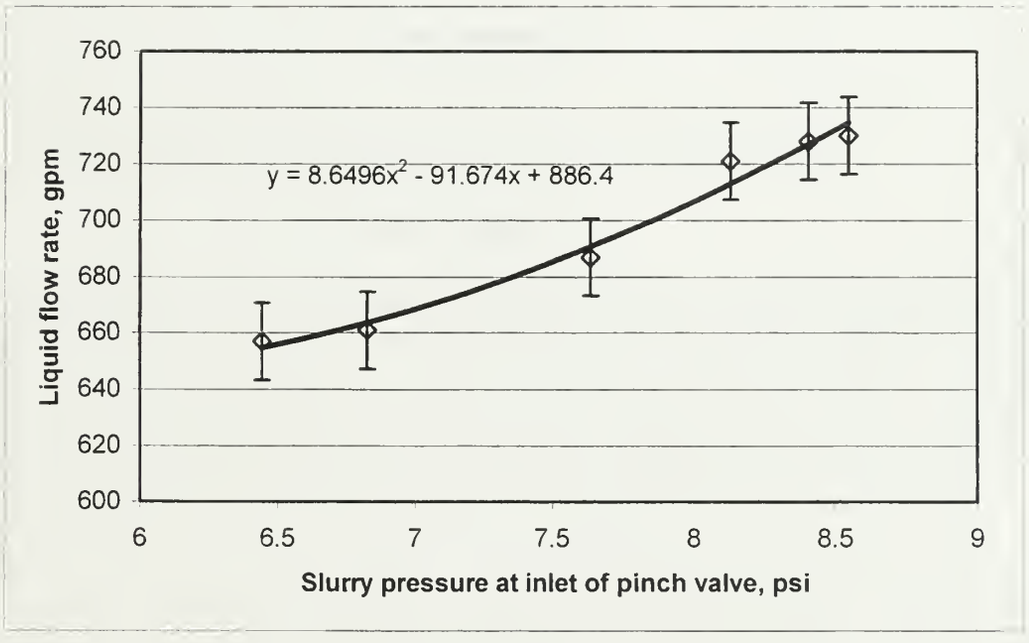

Figure 9. Slurry tank flow v. liquid pressure measured at inlet to pinch valve, broadcast applicator device.

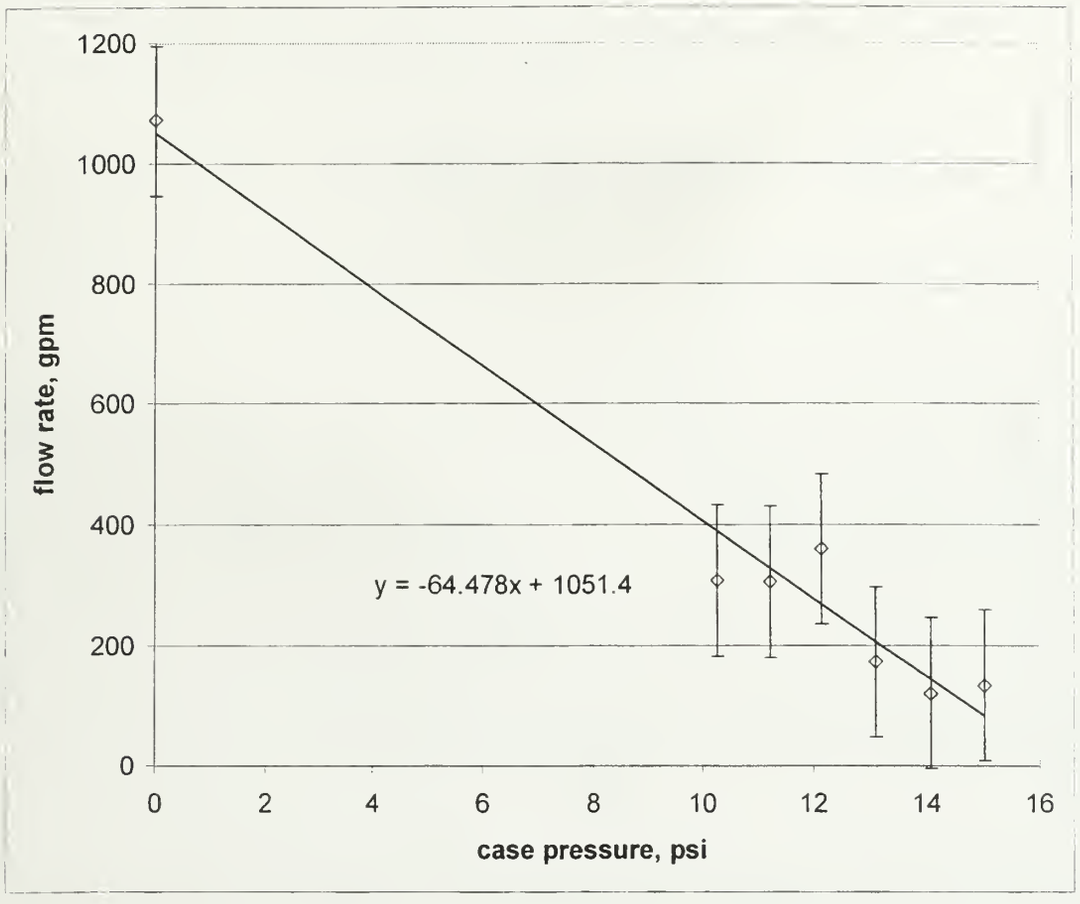

Figure 10. Slurry tank flow v. 6" valve case pressure for soil injection toolbar.

DISCUSSION

The prototype variable rate system could be used for existing tankers, or for towed-hose applicators as an add-on lower cost control system linking ground speed sensing with magnetic flow meter installations. The pneumatic pinch valve might also be used as a "soft-closing" end-of-row shutoff mechanism to reduce manure surface run-on during turns. Manure spillage at end rows is a common problem with pump-supplied towed hose systems and shutoff valves for toolbars are an expensive option that requires a pressure-rise cutoff at the supply pump.

Temporal response of the system, i.e. the ability to quickly follow changes in controller demand with increased or decreased slurry flow, must be addressed but is not simple to implement, due partly to the size of the valves being actuated. An example of laboratory tests of a 4-inch pinch valve's temporal response with the Marsh-Bellofram I/P transducer is shown in Figure 12. Field test response of the 6" valve on the slurry tanker was similar. The lab and field test series were done without closed-loop feedback; a feedback loop could greatly increase (i.e. degrade) response time depending on the control hardware and software. Response is dependent on air supply pressure; typical response at 60 psi supply pressure to a step input (settling within 10% of the new setpoint) was about four to six seconds (similar to results produced by experimental equipment reported in Morris et al. 1999), and performance degraded quickly as supply pressures fell below 60 psi. Inspection of the pressure v. time plots of the laboratory tests indicates that the system is underdamped, and could perhaps be optimized for field installations with little effort.

With a vehicle traveling at only 5 miles per hour, it would take about 40-50 feet for the application rate to respond to a step input and stabilize at the new rate.

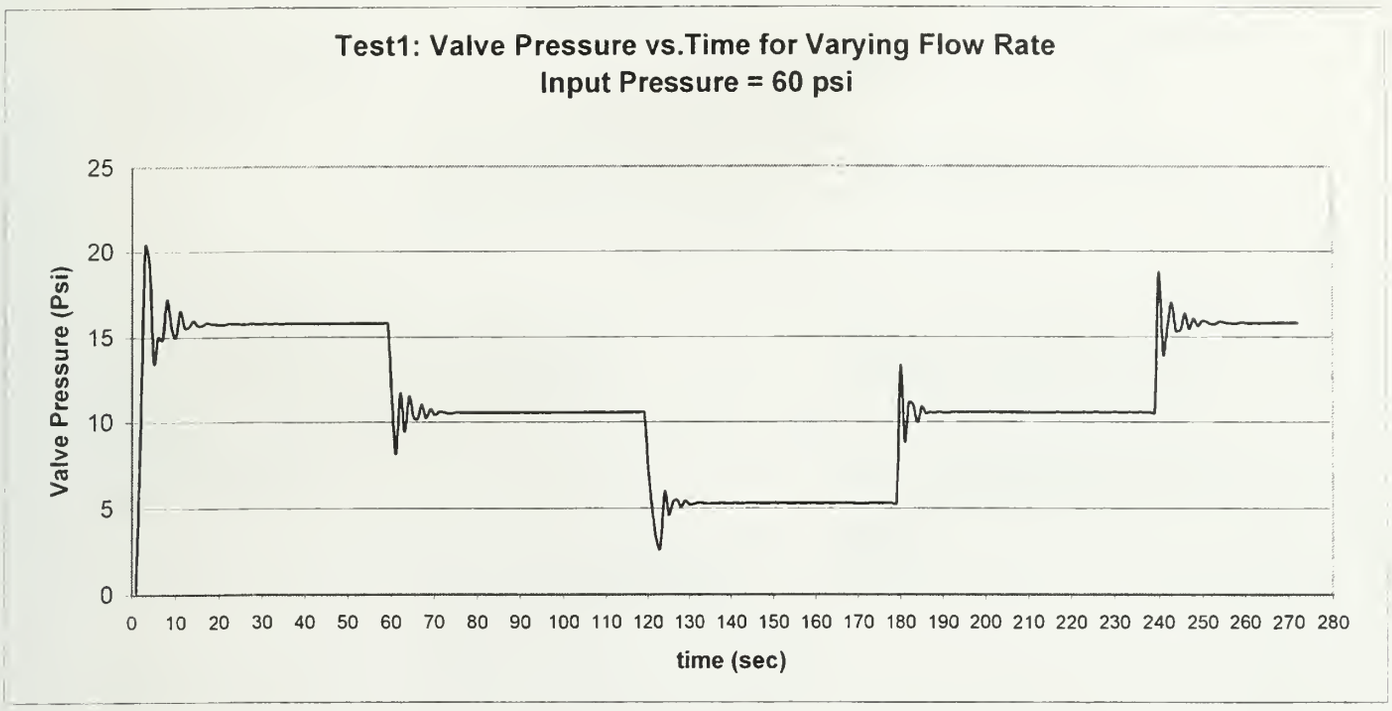

Figure 11. Typical time response of Marsh-Bellofram current-pressure transducer and 4" pinch valve to step inputs. Open loop control. Tests show a typical response time of about four to six seconds.

RETROFIT VARIABLE RATE SYSTEM

Major capital expense items for building the system on an existing tanker are the pneumatic pinch valve, the air compressor system, the radar ground speed sensor, on-board rate controller, and the I/P transducer (electronic air pressure regulator) (Table 1).

Fabricating the system, while it is not complicated, will require standard mechanical and electrical skills, with special attention required for dust and water proofing the pneumatic supply and control systems. Machine-specific calibration will be required, with a series of steady-flow test runs on either a full tank of slurry (valve case pressure and tank headspace pressures held constant) or with a partial tank and truck scales to determine net change in tank weights over time. A chart of case pressures v. flow rate must be constructed, from which the automatic controller can be programmed. If the pressure-sensing system is installed, it can be used to fine-tune and track system performance over time. However, our tests have shown that an open-loop system, i.e. with no pressure feedback to the controller, is simpler and probably adequately accurate.

Longevity of the pneumatic pinch valve liner is not known. Replacement of the liner is a straightforward shop disassembly/reassembly procedure. Our experience with the oil-less 12 VDC air compressor is limited but indicates that the piston/cylinder wears out rather quickly and air supply diminishes to an unacceptable level. Therefore we recommend consideration of a continuous-duty vehicle air compressor (necessarily more expensive than the 12 VDC model) where possible.

Table 1. Components list for retrofitted variable rate system incorporating pneumatic pinch valve, radar ground speed sensing, and air bleed pressure sensing.

Qty.	Item	Specifications	Comments
1	6" Type A Red Valve pneumatic pinch valve or equivalent		size depends on tank discharge pipe diameter; 6" most common)
1	Air compressor	100 psi continuous, ___ SCF minimum at 60 psi.	12 VDC powered, or tractor mounted belt-driven (preferred).
1	Air tank	10-15 gallon minimum, 200 psi rated.	
1	Line filter and condensate drain		
1	Current-to-pressure (I/P) transducer (electronic air pressure regulator);	0-5 VDC input 0-30 psi output.	Marsh-Bellofram Model 2000 S or equivalent. Match input to rate controller output specification.
1	Dust tight and water tight enclosure		Some enclosure functions can be combined into larger boxes if needed.
1	Rate controller	Match I/O specifications to ground speed sensor, I/P transducer, etc.	Raven, etc.
1	Radar ground speed sensor	Standard 0-5 VDC output, speed range appropriate to tractor/implement combination	
2	Air bleed orifice assembly in copper tubing	.020" orifice spray nozzle disc, stainless steel	For optional air bleed pressure sensing circuit
3	Differential air pressure sensors; tank headspace to pinch valve inlet, valve inlet to outlet, and valve outlet to atmosphere	0-30 psi, 12 VDC excitation voltage, 0-5 VDC output. Omega Engineering model # PX 137-030 DV or equivalent	For optional air bleed pressure sensing circuit.
	Tubing, fittings	Air lines suitable for 100 psi (high pressure side) or 30 psi (low pressure sensing circuit)	High pressure lines connect compressor, air tank, and I/P transducer. Also supply optional air bleed pressure sensing circuit, high side.

CONCLUSIONS

Laboratory and field tests indicate that a pneumatic control system using off-the-shelf components can be used as the major mechanical component at any of the levels of control needed for nutrient management plan implementation – constant flow rate, constant per-acre application rate, GPS/GIS interfaced for precision application, and on-board nutrient sensing. The system fills a need for vacuum-loaded tankers, since a liquid slurry pump and magnetic flow meter are not needed.

ACKNOWLEDGEMENT

The funding support of the Illinois Council for Food and Agricultural Research is gratefully acknowledged.

REFERENCES

Funk, T.L. 2002. Flow measurement and control system for precision land application of liquid manure from vacuum loaded slurry tanks. ASAE Paper No. 002075. ASAE, St. Joseph, MI.

J. Robert, and Y. Zhang. 2002. Development of a practical variable rate system for vacuum loaded slurry tankers. ASAE Paper No. 021100. ASAE, St. Joseph, MI.

Funk, T.L., M.J. Robert, Y. Zhang, and R.E. Fonner. 2003. Precision and Accuracy in a Nutrient Management Plan Utilizing Liquid Manure Application: Expectations and Reality. ASAE Paper No. 032158. ASAE, St. Joseph, MI.

Morris, D.K., D.R. Ess, S.E. Hawkins, and S.D. Parsons. 1999. Development of a site-specific application system for liquid animal manures. Applied Engineering in Agriculture 15(6):633-638.

Overview of Methods to Reduce Odorant Emissions from Confinement Swine Buildings

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INTRODUCTION

Odors are emitted from a variety of sources in swine production facilities. A large quantity of odorants can be emitted from manure handling and storage facilities. However, swine production buildings can also emit significant levels of odorants. This is especially true if manure is held within the buildings for periods exceeding 4-5 days. Manure also sticks to floors, walls, equipment, and pigs. Feed is often spilled in areas where pigs don't clean it up. This manure and feed can be around for several days or weeks and release highly objectionable odorants if these organic materials break down under anaerobic conditions. The amount of surface area of these odorant sources can be large and lead to high emissions of odorous gases. To further complicate matters, swine buildings usually have high concentrations of dust in the air and odorants adhere to the dust so the dust can also carry odors out of the buildings (Hoff et al., 1997a).

Hundreds of different gaseous substances are produced within swine buildings. Fortunately, most of these substances are not odorants and do not produce a negative response from most people who smell them. The most important constituents of objectionable odor from the breakdown of organic material in swine facilities appear to be indole, p-cresol, phenol, skatole, volatile organic acids (acetic, propionic, isobutyric, butyric, isovaleric, valeric, caproic, and heptanoic), and ammonia. The level of swine odor is not closely related to the levels of ammonia or hydrogen sulfide in the air (Sweeten et al., 2001). A fairly authentic swine odor can be created artificially in the laboratory by combining fewer than 20 substances in the right proportions (DeSpirito et al., 1999). Many of these same substances can be combined in different proportions to create very different aromas, so the presence of a particular group of substances does not necessarily mean that there will be a specific odor response in humans. The odor detection concentration for humans is very low for many of these substances, so they have to be diluted to very low concentrations before the sensation disappears.

Swine buildings also have significant levels of airborne dust. Most of these particles are organic (80-90% feed, 2-8% manure, 2-12% from the pigs) but are not highly odorous by themselves. However, gaseous odorants in the air will readily adsorb onto the particles and will be re-emitted from the particles for relatively long periods after the particles leave the swine building. Although, the amount of odorants on the particle may be small relative to the gaseous quantities. particles behave very differently in the air than do gases and can have very different odor transport characteristics relative to gaseous odorants. Once air from swine buildings is exhausted

to the outside, the gaseous odorants will be diluted to undetectable levels relatively quickly under most Illinois weather conditions. However, dust particles do not disperse as readily and each particle can carry concentrated amounts of odorants on their surface for relatively long periods. If you also consider that human response to these odorants varies widely among people, it is easy to see why odor measurement and control is a complicated subject.

Unfortunately, people are very sensitive to these odors and you may need to reduce the odor emissions substantially before the odor levels become acceptable at locations immediately adjacent to the swine buildings. Probably, the best strategy is to reduce emissions of odorants sufficiently so they will dilute to more acceptable levels at a shorter distance from the facilities. There is usually a cost to implement and maintain management and technological means of reducing odor emissions. The amount of investment that a producer may wish to make in odor control will vary considerably with their circumstances.

Odorants are emitted from a number of sources in swine production facilities (Miner, 1995). Consequently, odor control will usually require the application of several control strategies at once so all the major sources can be addressed. Each facility needs to be analyzed systematically and all the appropriate odor control strategies applied to counter each of the large odorant sources in that facility. The odor reduction technologies applied must be compatible with the management capabilities at the facility. Technologies or methodologies that exceed management capabilities will be poorly managed or eventually abandoned. There are several strategies that have been be applied to reduce odor emissions from swine facilities, and I will discuss some in the following text.

Separation Distance

Odorous gases and dust dilute to lower concentrations as the odorous air moves and mixes with the surrounding air. The more distance between the swine facilities and people's homes, the greater the opportunities for dilution and the lower the odor perception. If building exhaust air can be mixed with more surrounding air, then it will dilute odors. Some swine producers have planted trees or installed other obstructions such as large walls between the swine facilities and neighbors in hopes of getting more air mixing (Bottcher, et al., 2000). Other industries exhaust contaminated air from high stacks or chimneys to get better mixing of the contaminated air with clean air before it moves back down to the earth's surface. Computer modeling by Williams (2003) has indicated that the exhaust may need to be 5-10 m up before it does much good.

Odors move primarily with the wind, but can flow down land slopes (air drainage) as air is cooled during the night. It is best to locate swine facilities where prevailing winds and air drainage downhill on calm nights will not carry odors to neighbors. Shield swine production units from the view of the general public. Keep the facilities clean, neat and in good repair to present a good image. Maintaining good relationships with the neighbors helps reduce conflicts.

Reduce Emission of Odorants at the Source

It is typically much easier to control odorant emissions at the source than to try to remove them from the air after they have volatilized. Removing low concentrations of specific gases from the large quantities of air that move through swine buildings is a daunting task. Strategies for reducing emissions at the source include removing the source from the building, diet modification, manure additives, coating or covering the source, and reducing the surface area of the source exposed to the air.

Building and Environmental Factors

Miller et al. (2003) studied 26 swine production buildings on 10 farms and related a number of factors to odor levels being emitted from the building. This study measured the increase in odor level as air moved through the buildings from the air inlets to the fan exhausts. Following is a summary of some of the relationships found in this study.

- Temperature and humidity – As temperature and relative humidity increased, odor level decreased. This could be at least partially related to the higher ventilations rates that occur as temperatures increase.
- Pig density – Fewer pigs per unit floor area reduced odor levels.
- Pig health – When pig health was good, odor levels increased.
- Air cleanliness – Buildings with cleaner air had lower odor levels.
- Pit depth – If pits were deep (greater than four feet) and had a three feet depth of manure or less, then odor levels were reduced.

Cleaning Facilities

A simple and relatively low cost method of reducing the amount of odor source that is exposed to the air is regular and thorough cleaning of all surfaces that may have exposed manure. This includes the pigs themselves since they often have manure on their hair and skin. Manure should be removed from the building often—every 3-4 days. Studies have shown that odorous sulfur compound emissions from swine buildings increase quickly 4-5 days after the last cleaning and substantially drop immediately after the building is cleaned and manure removed from gutters. One of the most effective odor control methods is to remove all manure from the buildings often and store in covered outside tanks. The building should be designed specifically to make it easy to clean. Smooth surfaces, good manure handling facilities, and easy worker access to all areas for cleaning will help this process.

A study was conducted at the University of Illinois on the effect of room washing on reduction of gases, dust and odor in swine buildings. The treatment room was washed daily with a commercial power washing machine to wash the pens, fences, floors, and walls up to a height of 4 feet. The daily washing resulted in a reduction in ammonia, odor intensity, and sulfur based volatile organic compounds in the air. However, dust concentrations were not clearly influenced by daily room washing. Pig growth performance was negatively affected by the daily washing. Although washing rooms on a daily basis in large facilities is not considered to be practical, it does show that there may be some potential of odor reduction by keeping surfaces clean. On the

other hand, Miller et al. (2003) found that as building cleanliness improved, odor levels increased. The key is reducing the surface area exposed to the air of organic material undergoing anaerobic decomposition. The amount of dry manure exposed to the air may have relatively little influence on odor levels.

Sprinkling Small Amounts of Oil

Studies have shown that sprinkling a small amount of vegetable oil on floor and pen surfaces, and on the pigs can significantly reduce dust levels (50-80% dust mass reductions) in swine buildings. Claims have been made that it also reduces the emissions of odorous compounds into the air. It is generally believed to reduce health problems in workers and animals, primarily because of the dust reduction. A recent study at the University of Illinois showed that oil sprinkling reduced dust concentrations by over 50% without any detrimental effects on pig performance (Anderson, 2002). It is important that the oil be applied at low pressure to form relatively large droplets that fall from the air onto the surfaces. If the oil is applied at high pressure, it tends to form a fine mist that gets into the worker's and animal's respiratory systems. Midwest Plan Service (MWPS, 1997) recommends sprinkling 40 mL/m^2 of floor for the first two days; 20 mL/m^2 the second two days, and 5 mL/m^2 for the rest of the time the pigs are in the building. Smaller facilities could apply the oil with a hand sprayer. Automatic oil sprinkling systems are being developed for larger facilities but many oils tend to transform into a gum which plugs sprinklers.

Removal of Gaseous Odorants from Air

Dust Removal

Since odorous compounds can adhere to dust particles, it is conceivable that odor levels could be reduced by removing dust. In fact, some industrial processes use a dry scrubbing method where particles are added to the air to adsorb chemicals in the air, then the dust is removed which also removes the chemicals. Most swine buildings already have high concentrations of dust in the air that should be capable of adsorbing significant amounts of odor. Removing dust from the air is a challenge because the high concentrations quickly clog dust filters and the small dust sizes are difficult to capture by existing commercial centrifugal cleaners. An aerodynamic deduster has been developed with the help of C-FAR funding, which can remove many of the small particles with little pressure drop across the unit, and it requires little maintenance. Two dedusters were attached to an air recirculation system in a swine building and reduced dust mass concentrations in the air up to 50%. Odor levels were not measured.

Wet scrubbers have also been developed for removing dust from the air of ventilation fans before it is exhausted to the atmosphere. To be practical, these units would need to have little restriction on airflow and would need a system for cleaning the water so it can be recycled. A unit developed at the University of Illinois, reduced fan performance less than 1.5% and removed around 80% of dust mass from the air. The water also adsorbs water soluble compounds form the air and the wet scrubber was found to remove 1/3 to 2/3 of the total volatile organic compounds from the air depending on the amount of water used and the contact time allowed between the water and air.

The reported amounts of odor reduction due to dust removal vary widely in the literature (~0% to over 90% reductions). Dr. Steve Hoff and colleagues at Iowa State University tested various biomass air filters made from field residue on the ventilation exhaust of a swine nursery building and found significant dust and odor reductions (Hoff et al., 1997b). Dust removal varied between 45 and 75% with subsequent odor threshold levels dropping by 50-90% between inlet and outlet of the filter. Zhao et al. (2001) found only an 8% reduction in odor intensity with a wet scrubber that removed around 84% of the dust.

There are, no doubt, a number of contributing factors that are not being accounted for across these studies. Many of the odor-measuring methodologies filter out particles in order to reduce complications in the process, so they may or may not account for the contribution of particles in the first place. This could confound the effort to determine the effect of dust removal on reductions of odor perception. The amount of dust initially in the air of the swine building will also have a large effect. Removing 80% of low quantities of dust from the air will have less impact on odorant levels in the air than removing 80% of large quantities of dust, because larger amounts of dust will adsorb larger amounts of odorants. Another possible problem for wet scrubbers is that some of the odorants may react with the water to produce other odorants. For example, acetic acid, a prevalent organic acid in swine odor can react with water to be transformed to ammonium acetate which is another odorous compound. Williams and Muggli (2001) suggest that the addition of common baking soda (sodium bicarbonate) to the water may help alleviate this reaction.

Biofilters

Biofilters can work well for removing odors and dust from the ventilation fan exhausts if properly designed and maintained (Nicolai and Janni, 2000). They have been used extensively for removing a number of compounds from air in industrial processes. Biofilters provide moist material with a great deal of surface area on which micro-organisms can grow. Air moves through the biofilter and odorants are adsorbed onto the material which allows the micro-organisms to degrade odorants to less odorous compounds. Biofilters can be constructed at a relatively low initial cost as has been demonstrated by the University of Minnesota. Their biggest problem is the large pressure drop across the biofilter media, which leads to high operating costs for high airflows. They are used mainly for low airflows that occur during cold weather ventilation of swine facilities. They are also difficult to manage since the media needs a continuous supply of moisture, heat, and energy source for the bacteria populations to thrive. They can be made to work well for the continuously operating cold weather fans, but the intermittent operation of the temperature control fans are a problem. Consequently, biofilters have been used in a very limited number of special applications.

Ozone

Ozone is a very reactive compound that is believed to reduce odor by breaking down many odorous compounds in the air. Ozone can be dangerous at certain concentrations because it can irritate the respiratory system. Most recommendations are that ozone levels not exceed 0.1 parts per million (ppm) in the air for humans. It is not known what levels are acceptable for pigs but the same limit is usually used in swine buildings because of the human workers. North Carolina

State University (Keener, et al., 1999) and the University of Illinois (Elenbaas-Thomas, et al., 2003) have studied ozonation of swine building air and the results are mixed. The North Carolina study found a reduction of ammonia and better pig performance with ozone. The Illinois study found that ozone application at the maximum concentration of 0.1 ppm did not have any statistically significant effect on bacterial count, dust mass concentration, ammonia concentration, hydrogen sulfide concentration, odor intensity, and sulfur compound concentration. Nor did it have any statistically significant effect on pig growth performance in terms of average daily gain and feed efficiency.

It is believed that the ozone reduces some of the odorous compounds but has little effect on others. Consequently, the characteristics of the odor may change but there is still a lot of odor being emitted. For example, the Illinois study found that sulfur compounds are not affected by ozone, but some of the other volatile organic compounds were reduced. Higher concentrations of ozone may have more of an effect on odor levels but health issues will limit this application. The University of Minnesota has tested the odor reduction potential of non-thermal plasmas that are also highly reactive with odorous compounds (Goodrich et al., 1999).

Catalytic Methods

Catalytic converters have been used for years for removing undesirable gases from car exhausts. They consist of a catalytic material that adsorbs gaseous molecules which are then slowly oxidized to harmless compounds. The type of catalytic material is selected based on the molecules that you want removed. Drs. Masel and Wiltkowski tested a copper catalyst for removing acetic acid from air. The tests showed good reductions if the airflow is carefully matched to the amount of catalytic material. High static pressures from moving air through the catalytic material will increase energy costs.

REFERENCES:

Anderson, B.K. 2002. Managerial and nutritional manipulation to reduce swine odor. Unpublised Ph.D. Thesis, University of Illinois at Urbana-Champaign.

Bottcher, R.W., K.M. Keener, and R.D. Munilla. 2000. Comparison of odor control mechanisms for wet pad scrubbing, indoor ozonation, windbreak walls, and biofilters. Paper No. 00-4091. ASAE International Meeting, Milwaukee, WI, ASAE, St. Joseph, MI.

DeSpirito, A.A., J.A. Zahn, D.W. Russell, E.E. Cooper, and J.L. Hatfield. 1999. Development of a standardized method for odor quantification from livestock wastes: Development of an odor index. Final report to the National Pork Producers Council.

Goodrich, P.R., Y. Wang, H. Ma, S. Deng, and R.R. Ruan. 1999. Odor destruction using a barrier discharge reactor. Paper No. 99-4034, ASAE/CASE International Meeting, Toronto. American Society of Agricultural Engineers, St. Joseph, MI. 9 p.

Hoff, S.J., D.S. Bundy and X.W. Li. 1997a. Dust effects on odor and odor compounds. Proceedings of the International Symposium on Ammonia and Odour Control from Animal Production Facilities. Vinkeloord, The Netherlands, October 6-10. pp. 101-110.

Hoff, S.J., L. Dong, X.W. Li, D.S. Bundy, J.D. Harmon, and H. Xin. 1997b. Odor removal using biomass filters. Proceedings of the 5th International Livestock Environment Symposium. ASAE, St. Joseph, MI. pp. 101-108.

Keener, K.M., R.W. Bottcher, R.D. Munilla, K.E. Parbst, and G.L. VanWicklen. 1999. Field evaluation of an indoor ozonation system fro odor control. Paper No. 99-4151, ASAE/CSAE International Meeting, Toronto. American Society of Agricultural Engineers, St. Joseph, MI.

Miller, G.Y., R.G. Maghirang, G.L. Riskowski, A.J. Heber, M.J. Robert, and M. Muyot. 2003. Management and other factors that influence air quality and odor. University of Illinois Pork Industry Conference on Swine Odor and Manure Management. Champaign, IL.

Miner, J.R. 1995. A review of the Literature on the Nature and Control of Odors from Pork Production Facilities. The National Pork Producers Council, Des Moines, IA.

MWPS. 1997. Sprinkling oil to remove dust, odor, and gases in swine buildings-AED 42. Midwest Plan Service, Ames, IA.

Nicolai, R.E. and K.A. Janni. 2000. Designing biofilters for livestock facilities. Proceedings of the 2nd International Conference on Air Pollution from Animal Operations. Des Moines, IA. p. 376-383.

Sweeten, J.M., L.D. Jacobson, A.J. Heber, D. R. Schmidt, J.C. Lorimor, P.W. Westerman, J.R. Miner, R. H. Zhang, C.M. Williams, and B.W. Auverman. 2001. Odor mitigation for concentrated animal feeding operations. White Papers for the National Center for Manure & Animal Waste Management, Midwest Plan Service, Ames, IA.

Elenbaas-Thomas, A.M., L.Y. Zhao, Y. Hyun, B. Anderson, G.L. Riskowski, M. Ellis, and A.J. Heber. 2003. Effects of Ozonation on Gas, Dust, Bacteria Levels and Swine Growth Performance. Submitted to Transactions of the ASAE.

Williams, A. and J. Muggli. 2001. Atmospheric dispersion of swine odor from confinement buildings and lagoons: preliminary results. Five Year Progress Report to the Illinois Council on Food and Agricultural Research (C-FAR).

Williams, A. 2003. Dispersion modeling of hog-odor transport. University of Illinois Pork Industry Conference on Swine Odor and Manure Management. Champaign, IL.

Zhao, L.Y., G.L. Riskowski, P. Stroot, M. Robert, and A.J. Heber. 2001. Development of a wet scrubber to reduce dust and gaseous emissions from swine buildings. Paper No. 01-4075. ASAE International Meeting, Sacramento, CA, ASAE, St. Joseph, MI.

Odor Management in Swine Finishing Operations: Cost Effectiveness*

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The purpose of this paper is to investigate the cost effectiveness of the odor control strategies identified to be important in reducing odor emissions from swine finishing buildings by Miller et al. (2003). Cost effectiveness analysis in this paper evaluates the marginal reduction in odor emission rates relative to the increase in production costs per market hog sold due to the application of an odor management option. Miller et al. (2003) examined the effects of different practices and building characteristics controlled by management on odor emitted from pig finishing buildings. Results showed that greater pig space, air treatment, shallower manure depths, and the use of deep pits reduced odor emission rates of swine finishing buildings. Specifically, the odor emission rate measured at a deep pit building, assuming other factors were held constant, was 0.17 log OU/h lower than that at a shallow pit building; an increase of one m^2 in pig floor space decreases the odor emission rate by 0.25 log OU/h; one additional meter (3.3 ft.) of manure depth increases the odor emission rate by 0.26 log OU/h; and improving observed air dustiness (another study variable) by one decreases odor emission rate by 0.07 log OU/h.

Cost Effectiveness of Increasing Floor Area Per Pig. The cost of using floor space for odor management arises from the decrease in the number of hogs marketed and hence the returns to production. Assuming that the odor management strategy is to increase floor space per pig by 10% for a typical 1,020-head finishing barn with pig density of 0.74 m^2/pig, the total cost due to reduced production is $5,607/yr, or $2.22 per marketed hog.

Cost Effectiveness of Improving Air Quality. Air quality was measured as subjective impressions of air dustiness on a scale of 1 (very clean) to 10 (very dusty). Totally, five air treatment technologies were examined: manual oil sprinkling, automatic oil sprinkling, wet scrubbing, diffusion-coagulation-separation (DCS) dedusting, and evaporative misting. According to the existing literature and our own estimations, the costs (per marketed hog) of applying these technologies are $0.87 for manual oil sprinkling, $0.51 for automatic oil sprinkling, $0.54 for wet scrubbing, $0.66 for DCS dedusting, and $0.30 for evaporative misting, respectively. Based on their dust removal efficiencies, the effects of these technologies on odor emission reduction were estimated as 0.42 log OU/h for oil sprinkling, 0.28 log OU/h for wet scrubbing, 0.49 log OU/h for DCS dedusting, and 0.21 log OU/h for evaporative misting.

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* *Paper presented at the **University of Illinois Pork Industry Conference**, Champaign, IL **December 11-12, 2003**.*

Cost Effectiveness of Reducing Manure Depth in Shallow Pit Systems. The strategy of reducing manure depth is limited to shallow pit systems because for deep pit systems, manure is removed once or twice a year and timing is often influenced by weather and other variables. For shallow pit systems, reducing manure depth is simply a matter of scheduling. Since cost effectiveness is based on comparisons, the efficiencies and costs of two alternative manure depth reducing strategies were compared. The two alternatives considered were flushing the pit weekly versus biweekly and their costs were estimated as $0.12 and $0.06/marketed hog, respectively. Based on manure generation data in the ASAE Standard, manure depth in the pit will increase by about 0.05 m every week. Therefore, the efficiency of weekly flushing compared with biweekly flushing is 0.26*0.05 = 0.01 log OU/h. The annualized cost difference between the two strategies is $0.12 - $0.06 = $0.06 per pig marketed.

Cost Effectiveness of Deep vs. Shallow Pit Systems. When the contribution of manure depth to odor is accounted for, deep pit systems were shown to have a lower odor emission rate than shallow pit systems. However, the odor advantage of deep pit over shallow pit systems can be reversed if manure depth in a deep pit system is 0.65 m greater than in a comparable shallow pit system. Assuming that a typical shallow pit is recharged with 0.3 m recycled lagoon effluent, the manure depth in the deep pit that may cause it to have higher odor than a shallow pit is 0.95 m. The cost of a deep pit system is $0.63/marketed hog higher than that of a shallow pit system when facility, manure removal, and land application costs are all taken into account. Keeping manure depth less than 0.95 m in a deep pit may not entail additional costs as long as the manure removal costs are based solely on manure volume, but it requires that manure be removed from the pit three times a year. The *average* manure depth over the year in the pit in this case is 0.48 m. The odor reduction efficiency of a deep pit building compared with a shallow pit building flushed once a week then is 0.13 log OU/h. Hence, the cost effectiveness of a deep pit system relative to a shallow pit system with lagoon can be obtained as 0.21 log OU/h per dollar per marketed hog. This of course assumes no influence from weather or crop cycles that would prohibit land application of manure. It is unlikely that this is technically feasible in much of the Midwest. However, removing manure twice a year still gives deep pit systems an advantage in reduced odor emissions from buildings on average because the average manure depth in the pit in this case is 0.72 m.

SUMMARY

The rank of most cost-effective (those to use first) to least cost-effective (those to use last) for these alternative strategies is: automatic oil sprinkling > DCS dedusting > evaporative misting > wet scrubbing > manual oil sprinkling > deep pit building removing manure three times a year > draining shallow pit weekly > deep pit building removing manure twice a year > 10% increase in square meters per pig. The symbol ">" means "*is preferred to*."

REFERENCE

Miller, G.Y., R.G. Maghirang, G.L. Riskowski, A.J. Heber, M.J. Robert, and M. Muyot. 2003. Influences on air quality and odor from mechanically ventilated swine finishing buildings in Illinois. *Transactions of the ASAE* (in review).

Land Application Considerations in Managing Swine Manure

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ABSTRACT

Geographic concentration of production in the swine industry seems increasingly at odds with the fundamental expectation that swine manure will be land applied, safely and according to sound agronomic principles. This tension is evident, in part, in a growing regulatory oversight concerned that both the difficulty of land application of manure and the risks associated with failure increase as the size of operation increases.

Since land applying animal manure is required, a given swine production facility implies a predictable landscape *footprint* – i.e., the minimum amount of land required to safely absorb and recycle the nutrients in the operation's waste stream. The objective of this paper is to further develop the landscape footprint concept and use it as a framework to discuss aspects of swine manure management, including: regulatory guidelines, agronomic recommendations for crop nutrients, economic considerations, geographic concentration of feeder operations, and policy concerns. Results of a manure management planning exercise suggest that the value of fully using the nutrients in swine manure can significantly exceed the cost of application, and that full use of the nutrients requires a much larger footprint than a cost-minimizing disposal strategy typical of many current operations. Important implications of these results are the need for greater dispersal of production facilities and the need to re-integrate swine production with crop production.

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INTRODUCTION

In concept, the basic manure management strategy for confinement animal production is straightforward: contain manure safely until it is land applied, and then land apply it to prevent both off-site movement and excessive on-site accumulation. While there are important variations of this strategy currently in practice, the basic expectations are universal regardless of size, type, or geographical setting of the animal enterprise.

In the case of swine production, this basic strategy is a legislative mandate (e.g., in Illinois see 510 ILCS 77/1 *et seq.*). Underlying the strategy are assumptions that the soil organisms will decompose the manure and crops grown on the land will consume and, thereby, recycle the constituent nutrients. This underlying recycling process means: 1) the capacity of the land to absorb swine waste is limited by the soil's biological activity and crop productivity, and 2) the rate (pounds/acre/year) at which manure can be applied is determined by the nutrient whose crop utilization rate is first satisfied by the manure application.

The reliance of swine production on land application of its manure stream means that each production facility demands some characteristic minimum area of land. The minimum acres of cropland needed to appropriately dispose of the manure produced, year after year, can be viewed as that facility's manure disposal *footprint*. As the swine industry has continued to concentrate production into fewer, larger facilities, the localized problem of manure handling and disposal, including the size of the footprints required, has intensified.

Earlier investigations have confirmed that there are localized problems of nutrient imbalances in the soils of manure application sites. These problems have been documented in areas of intensive animal agriculture, such as eastern Pennsylvania (Young et al. 1985), north-central Iowa (Jackson, Keeney and Gilbert 2000) and more generally throughout the U.S. (Gollehon and Caswell 2000). These studies suggest problems due to local circumstances where the crop production at the application site is unable to fully utilize the nutrients in the waste stream of the animal production enterprise.

Continuing geographic concentration of swine production makes it more difficult and more expensive to properly land apply manure quantities being produced. One consequence is growing government oversight of manure management. This oversight reflects a concern that difficulties of implementing manure management strategies and the magnitude of the risks associated with their failure increase as the size of operation increases. Our study develops the concept of the facility *footprint*, and uses it to examine the localized economic and resource implications of swine production manure streams. While manure streams differ among types of swine operations (e.g., farrowing versus finishing operations), and vary over time, there are common characteristics among them and some general observations to be made.

THE FOOTPRINT

The concept of a swine facility *footprint* specifies the *number of acres* needed to properly land apply the facility's waste stream. While the actual layout of a disposal area can vary depending on the setting of a particular facility, the factors involved in determining the size of the footprint can be generalized. The generalizations are relevant to the profitability of the production facility, to proximity of other residents in the vicinity who may be impacted, and to the extent of the affected environment.

The factors to be considered in determining the footprint are: characteristics of the waste, how it is affected by handling, and the absorption and recycling capacity of the soil on which it is applied (Equations 1and 2). In the end, the total amount of land required (L_I), will be controlled by one nutrient. This is reflected by recognizing the maximum L_i over all nutrients (i), as a limit.

$$L_I = \underset{i}{Max}\, L_i \qquad (1)$$

$$L_i = f(Q, M_{i:T}, S, N_i) \qquad (2)$$

Where:
L_I = area of cropland required to accommodate all nutrients;
L_i = area of cropland required for each nutrient i;
Q = quantity of manure produced;
$M_{i:T}$ = content of nutrient i in manure, for a given manure handling technology (T);
S = yield potential of the soil; and
N_i = needs of crop(s) for nutrient i.

Q, M – Amount and Nutrient Content of Manure

The amount of manure generated by a swine facility is a function of the number and the growth stage of the hogs. What determines the amount of land needed for application is the mass of the various nutrients present. The volume of water in which the nutrients are carried is of secondary concern. Except in rare situations where the hydraulic capacity of the soils receiving the manure can be exceeded before nutrient limits are reached, the water is basically an inert carrier, and is of concern only in terms of its cost to handle, which is considered here, and its value as irrigation water, which is not.

The nutrient content of the manure stream of a swine finishing operation can be affected by a number of variables involved with a choice of manure management strategy, including the technology used to collect and store the manure (Overcash, Humenik and Miner 1983). For a given manure management strategy, as the nutrient content of the manure stream increases, the size of the land application footprint increases (i.e., $\partial L_I / \partial M_{i:T} > 0$).

From an agronomic perspective, this relationship holds independently for each of the three macro-nutrients: nitrogen, phosphorus and potassium. Pertinent regulations speak primarily to

limitations regarding nitrogen, but concerns about the build-up and impact of phosphorus are increasing (510 ILCS 77/1 *et seq.*). Potassium appears to be of no regulatory concern.

However, all nutrients have potential economic value. Failure to account for this value can result in less than optimal resource allocation.

Manure Management Strategy (*T*). How manure is collected, stored and land applied varies among swine operations. Most confinement facilities handle manure as slurries. Whether the swine operation is using an anaerobic lagoon or a storage pit will significantly affect the nutrient content of the manure.

S – Yield Potential of the Soil

The practice of land application of animal manure is constrained by accepted agronomic principles. This implies that the soil nutrients are maintained over the long run and that manure is applied at a rate needed to replace nutrients removed by the crops grown. The rate at which the soil/crop system can utilize manure is dependent on the inherent yield potential of the soils involved; the more productive the soils, the higher the yields and, therefore, the more nutrients recycled. The more nutrients the soil can absorb and process, the fewer acres needed (i.e., $\partial L_l/\partial S < 0$).

N – Nutrient Use by Crops

Closely related to the productivity of the soil is the choice of crops used in the soil/crop nutrient recycling system. The higher the demand of the crop(s) for nutrients and the higher the yield, the smaller the area needed for manure disposal (i.e., $\partial L_l/\partial N < 0$).

Sustainable land application implies that the manure is being applied at a rate needed to replace the nutrients being removed by the crops. Since the nutrients in the manure are not in the same proportions as required by the crops being grown, the agronomic rate of manure application is determined by the nutrient which first reaches a 1:1 ratio between what is applied in the manure and what the crop will withdraw.

LAND ACCESS

The layout of the land application footprint of a particular production facility will depend on local circumstances. The acres required (L_l) may not be contiguous, and they may not adjoin the facility. This scattering of manure application sites has implications not only to the cost of land application, but also to extending the margin of possible contact between the applied manure and both the natural environment and human neighbors. Equation (3) illustrates an important relationship of this scattering due to non-contiguous access.

$$D = f(L_l, A) \qquad (3)$$

Where:
D = average haul distance;
L_l = area of accessible land required, from Equation (1);
A = *access,* accessible land as a percent of total area within the vicinity of the production facility.

The access term, A, reflects availability of appropriate land for manure application. Some areas more than others have conflicting soil conditions, topography, residential sites, etc. The access term accounts for success in acquiring the right, through outright land ownership or through contract with other landowners, to dispose of manure on land nearest the production facility. The greater the access to nearby disposal sites, the shorter the haul distance (i.e., $\partial D/\partial A < 0$).

LAND APPLICATION ECONOMICS

There are a number of factors determining the economic results of a given strategy for land applying manure, and factors affecting the value of the manure are not entirely the same as those affecting the cost. The value of a chosen strategy derives from the value of commercial fertilizer being replaced by nutrients in the manure. For nutrient i, under application strategy, T, the value can be described:

$$V_{i:T} = f(F_{i:T}, P_i) \qquad (4)$$

Where
$F_{i:T}$ = amount of nutrient i having economic value under management strategy T;
P_i = price of commercial fertilizer replaced by nutrient i;

In defining the footprint concept, Equations (1) and (2) described how interactions between a particular management strategy, a given manure stream, and characteristics of the surrounding landscape determine the area of cropland needed for appropriate land application. The same interactions determine how effectively the manure nutrients are utilized. The more manure nutrients used by crops, the greater the value of the manure (i.e., $\partial V_{i:T}/\partial F_{i:T} > 0$). The prices of commercial fertilizer nutrients replaced, P_i in Equation (4), include three macro-nutrients, nitrogen, phosphorus and potassium. As the prices of these commercial constituents increase so does the fertilizer value of the manure stream (i.e., $\partial V_{i:T}/\partial P_i > 0$).

The relationships captured in the footprint concept also affect the cost of land application. For a given land application strategy the cost can be described:

$$C_T = f(Q, D, T) \qquad (5)$$

Where
Q = quantity of manure slurry;
D = average haul distance, from Equation (3); and
T = chosen manure management strategy.

Whatever the management strategy, costs are minimized when the footprint is as *few* acres as the limiting nutrient *requires*, and as close to the facility as possible so that the haul distance is

minimized (i.e., $\partial C/\partial D > 0$). The footprint concept underlying D considers only mass flows of nutrients. Application cost is also affected by the gross volume of the manure stream and the technology used to deliver it to the land.

As the volume of the manure stream increases, regardless of the nutrient content, the application cost increases (i.e., $\partial C/\partial D > 0$). The influence of technology on the disposal cost is not so obvious. The set of discrete choices of manure storage and handling technologies influences the costs both directly and indirectly. The indirect effect comes through the influence that a chosen technology has over nutrient content of the manure, $M_{i,T}$ in Equation (2), which, in turn, affects the haul distance, D, through Equation (3). However, the adopted technology, T, also affects the cost directly through differences in manure handling efficiency. This kind of efficiency advantage tends to be scale sensitive. Larger production facilities producing larger manure streams can use larger, more efficient equipment, particularly if an anaerobic lagoon is being used (Roka and Hoag 1996). For example, dilute effluent from a lagoon can be handled with large pumps and pipelines more easily than can storage pit slurry which has a higher concentration of solids. Where regulations and local circumstances allow surface application, dilute lagoon effluent can be land applied relatively cheaply using irrigation technology.

And, finally, the net economic result, *NER,* of manure management is the fertilizer value realized from the all of the constituent nutrients minus the cost of applying the manure stream. As shown in Equation (6), each alternative management strategy can generate a unique result.

$$NER = \sum_i V_{i,T} - C_T \qquad (6)$$

From a management perspective, strategies for land application of manure can be viewed along a spectrum of choices between minimizing the cost of disposal, on the one hand, to maximizing crop fertilization, on the other. Hoag and Roka (1995) discussed similar contrasting perspectives, which they associated with regional differences between North Carolina, with relatively fewer potential disposal sites capable of growing high value crops, and Iowa, with relatively many more such potential disposal sites. The suggestion is that *a priori* management perspectives influence how agronomic principles are interpreted and regulatory requirements are implemented and, to a considerable extent, constrain the economic consequences.

Manure as Waste

A view that manure is a waste to be disposed of at least cost presupposes that any value of the manure is small enough that it will not affect the choice of management strategy. In terms of Equation (6), the reasoning ignores the $\sum V_i$ term and seeks a strategy, T, with the minimum cost. The anaerobic lagoon is a technology choice consistent with this cost-minimizing perspective. Processing swine manure through an anaerobic lagoon effectively pre-treats the manure before land application. The intention is to reduce nutrients in lagoon effluent, which reduces the amount of land needed for disposal and, thereby, reduces the cost.

Other considerations. The capacity of land to assimilate swine manure and recycle nutrients depends on the choice of crops being grown and the yields obtained. If the site is viewed as a waste processing facility, one would minimize the required land area by choosing crops to maximize nutrient uptake, rather than to maximize returns to a crop production enterprise.

Under regulations of the State of Illinois (35 IAC 560), operators are allowed to take advantage of the fact that legumes use nitrogen available in the soil before they fix it from the atmosphere. This allows for the legumes as well as non-legumes to be used to clean nitrogen from applied manure, but the nitrogen consumed by legumes is of no economic value, since the nitrogen fixing plants would have obtained it for free anyway.

Manure as Fertilizer

At the other end of the spectrum is a perspective attempting to physically and biologically maximize recycling of the manure nutrients – maximizing F_i in Equation (4). This effectively maximizes $\sum V_i$ in Equation (6), while ignoring C_T.

The maximum biological value of manure as fertilizer is realized by spreading it over as *many* acres as the most limiting nutrient *will support*. Note that in the case of simply disposing of manure as a waste, the acreage limitation was worded: "as *few* acres as the most limiting nutrient *requires*." One objective seeks to minimize the footprint needed, the other to maximize the footprint benefitted. Each objective implies a different set of practices and technology.

There is another important distinction between "manure as waste" and "manure as fertilizer" strategies. In the first instance, regulations identify only two relevant nutrients as potential pollution threats, nitrogen and phosphorus. Under a "manure as waste" strategy, only the crop requirements of nitrogen and phosphorus, and their concentrations in the manure affect the size of the footprint, L_I in Equation (1). In contrast, under a "manure as fertilizer" strategy, nitrogen, phosphorus and potassium all have fertilizer value so any one of them can expand L_I.

CONTRASTING EXAMPLES

As just described, the size of a facility's footprint is determined by interactions between site-specific circumstances and management choices. An example set of circumstances can illustrate how different management choices affect the outcomes. A spreadsheet simulation was developed for each of twelve alternative management scenarios.

Assumptions

The example manure stream is being produced by a 1,000 head swine finishing facility, occupied 360 days per year. The facility grows feeder pigs from a purchase weight of 65 pounds to a market weight of 250 pounds, with each production cycle requiring 130 days. This schedule

results in 2.8 production cycles per year, with resident animals assumed to weigh an average of 150 pounds.

Relative concentrations of nitrogen, phosphorus and potassium in manure remain essentially the same through all stages of the growth cycle, although the amounts excreted increase as the hogs grow (Table 1). Nutrient production can vary twenty percent above or below the values shown in Table 1, due to differences in diet, and the amounts of other material such as waste feed and supplements that enter the waste stream (Midwest Plan Service 1993).

Nutrient concentrations measured in fresh fecal matter, in manure storage pits, and in anaerobic lagoon effluent also differ (Table 2). There is some loss of nutrients during pit storage, but there is much greater reduction of nutrients through the digestion process in a properly functioning anaerobic lagoon, especially in terms of total nitrogen. If the lagoon is operating correctly, fecal matter is broken down, nitrogen is denitrified to N_2O and N_2 gases which escape to the atmosphere, and phosphorus and potassium are precipitated with the digested sludge to accumulate on the bottom of the lagoon.

The soils assumed to be available for land application of manure produce average yields of 150 and 50 bushels per acre for corn and soybeans respectively. These crops are grown in a two-year rotation.

Management Alternatives. Twelve different manure management scenarios are presented. These are various combinations of four factors important in determining the footprint needed to dispose of the manure stream. The factors are:

- manure storage (pit or anaerobic lagoon),
- land application rates (based either on regulatory requirements or on agronomic recommendations),
- limiting macro-nutrients (N, P or K determining the application rate), and
- scavenging by a legume (whether soybeans are used to scavenge nitrogen from land applied manure).

The twelve scenarios do not provide an exhaustive set of possible combinations. The outcomes of some other combinations would be redundant (e.g., if the application rate is determined by either phosphorus or potassium, whether soybeans are used to scavenge nitrogen has no effect on the outcome). Some other combinations would be internally inconsistent (e.g., regulatory requirements essentially ignore potassium). Nevertheless, the twelve scenarios do present a meaningful range of outcomes reflecting, at one end, a strategy to simply dispose of manure at minimum cost and, at the other end, a strategy to extract maximum fertilizer value.

Nutrient Content of Manure: Pit or Anaerobic Lagoon. Nutrient outputs differ between pit manure and anaerobic lagoon effluent (Table 2). These are average daily amounts of N, P and K produced by an average sized pig (150 lb), and then either stored in a pit or processed through a

lagoon. The annual volume of manure produced also differs between the pit (530,000 gallons) and the lagoon system (740,000 gallons), because of the additional dilution water needed to assure proper anaerobic digestion within the lagoon. The nutrient content and volume estimates are from 35 IAC 560, *Design Criteria for Field Application of Livestock Waste*. While there is considerable variation in estimates of these daily outputs, these numbers are being used to generate relative comparisons and the 35 IAC 560 source is authoritative, from a regulatory standpoint for Illinois.

Application Rates: Regulations or Agronomic Recommendations. The application rates being compared (Table 3) come from different sources, both developed for use in Illinois. The regulatory rates come from 35 IAC 560, and the agronomic rates in the table come from the *Illinois Agronomy Handbook.*

Role of Legume: Nitrogen Scavenger or Nitrogen Fixer. This is a special case of contrasting application rates. Manure application regulations (35 IAC 560) allow the assumption that legumes will scavenge nitrogen from the soil at rates comparable to the uptake by non-legumes. In the case of a manure disposal area growing a 2-year rotation of corn and soybeans, this assumption allows the same rate of manure to be applied to soybeans as to corn so that, if nitrogen is the limiting nutrient, the average annual rate of manure application can be doubled. However, the scavenged nitrogen has essentially no economic value, because soybeans would supply their own nitrogen anyway.

Since the *Illinois Agronomy Handbook* makes no such recommendation, the scenarios based on agronomic recommendations do not include options for using soybeans as scavengers. The scenarios based on agronomic recommendations do reflect release of nitrogen from manure over time. When manure is incorporated during or immediately after application, 50 to 60 percent of the total nitrogen in manure slurry is available for crop growth during the year following application. Approximately another 25% is available in the second year and another 10 - 15% in the third (Ill Ag Handbook, 1997-1998, pg 93).

Fertilizer Prices. The price for each nutrient is based on the price of the common commercial fertilizer that it is replacing. Prices per pound are: nitrogen, $.20; phosphorus, $.20; and potassium, $.14.

Cost of Application. Figure 1 illustrates the relationships between the cost of four land application technologies and the volume of manure being handled. These costs were obtained through a telephone survey of manure spreading businesses operating in Illinois. Without exception, the rate schedules for all technologies provided by the applicators surveyed based on volume of waste applied. Firms do add a hauling charge (e.g., 0.1 cent per gallon per 1/4 mile) for transporting manure to the disposal site, if the site is more than about a mile from the swine facility. At the volumes produced by the facility in our example, it is assumed that the disposal area is entirely within the one mile threshold, regardless of the scenario, so that the costs of spreading the annual manure streams are $5,300 for the pit system (530,000 gallons) and $5,875

for the lagoon system (740,000 gallons). The difference in cost is the additional dilution water in the lagoon system.

Three economic outcomes are computed for each scenario: the *per-acre fertilizer value* in the manure, the *total fertilizer value* of the manure stream for one year, and the *net economic result* in which the cost of application is taken into account. For all scenarios, all three nutrients are valued, but only to the level justified by agronomic recommendations. Regardless of the application rate permitted by regulatory guidelines, any nutrient amount applied in excess of agronomic need is of zero value.

RESULTS

Our scenarios include options available with manure storage pit systems and with anaerobic lagoons. The scenarios presented in Table 4 are discrete choices, not a continuum, but they illustrate a range of intentions from minimizing disposal cost on the left, to maximizing fertilizer reclamation on the right.

Size of footprint. A strategy to minimize the footprint results in needing as few as 30 acres with a lagoon system, or 100 acres with pit storage. At the other end of the spectrum, a strategy to obtain the maximum fertilizer value requires access to 278 acres for a lagoon system, or 343 acres for a pit. The large differences in the footprint have a number of economic and environmental implications.

Pit versus Lagoon

In all six land application strategies, the footprint size and gross value of applied manure are both significantly higher for pit storage. Digestion occurring in an anaerobic lagoon greatly reduces the nutrient content of effluent (Table 2), so footprint required is less – regardless of the land application strategy. Note also that fertilizer value is always less for the lagoon, and that the net economic results is persistently negative.

Furthermore, while nitrogen is permanently reduced in the lagoon through denitrification and loss to the atmosphere, phosphorus and potassium are largely precipitated and stored in sludge accumulating at the bottom of the lagoon. If one assumes conservation of mass for these nutrients, the example anaerobic lagoon will annually accumulate 6,480 pounds of phosphorus

(enough to fertilize 119 acres and worth $1,296), and 3,492 pounds of potassium (enough to fertilize 65 acres and worth $489).

Illinois regulations require that when lagoons are decommissioned, the sludge, just like the liquid effluent, must be disposed of through proper land application. Depending on how long the lagoon has been operating, the land needed for proper disposal will be greater, perhaps many times greater, than that area used to absorb the annual effluent production.

Over-application

As part of the assessment of the management scenarios, nutrient applications in excess of agronomic recommendations were computed. The results are shown in Table 5. Note that in no case is nitrogen applied in significant excess. Second, note that strategies in which nitrogen is limiting do over-apply both phosphorus and potassium, especially if a lagoon is used. The lagoon effectively strips effluent of most of its nitrogen prior to land application, but leaves significant levels of both phosphorus and potassium. Third, only by considering all three nutrients is over-application completely avoided.

Although permitted in the short-run by regulations, over-application of phosphorus creates a potential long-term problem. Regulations do limit the total amount of phosphorus that can be allowed to accumulate in the soil at a manure application site. The limit in Illinois is set at an average Bray P1 or Mehlich phosphorus soil test of 300 (510 ILCS 77/1 *et seq.)*. Once that limit is reached, further applications are restricted to phosphorus rates equal to crop removal rates. A manure management strategy applying lagoon effluent to a minimum-sized application site will have a relatively short life span (Table 6) before more land will be required to receive the ongoing annual output of phosphorus.

DISCUSSION

Our set of manure management options is incomplete, some choices are more realistic than others, and the scenarios are based on circumstances and regulations found in Illinois (Tables 4-6). However, these results are useful to illustrate implications of trends seen in the swine industry. A recent analysis of actual manure management plans from Iowa empirically confirms the general findings of our simulations (Jackson, Keeney and Gilbert 2000).

In the early-to-mid-1990s, nitrogen was the nutrient of concern (Roka and Hoag 1996), and the anaerobic lagoon was the cutting-edge manure treatment technology because it greatly reduces the nitrogen content (Sweeten 1998). An intended consequence of this technology choice was to minimize the area needed for land application, enabling hog production to be concentrated and located in areas of low soil productivity. Our simulations show that in all lagoon scenarios, the cost of land applying lagoon effluent is greater than the fertilizer value of the nutrients. This outcome is consistent with the accepted wisdom of the early 1990s (Roka and Hoag 1996,

Boland *et al.* 1999). As a result, a land-minimizing approach to manure application was justified because it minimized disposal cost of an economic negative, i.e., a waste.

However, the economics of this strategy are self-fulfilling. A "cost minimizing" strategy is justified because the nutrient value of manure is not worth the cost of application. However, the nutrient value of the manure is a fraction of what could be realized, because the strategy: 1) minimizes nitrogen content of manure, 2) delays the availability of the phosphorus and potassium by storing them in lagoon sludge, and 3) still over-applies phosphorus and potassium beyond

crop needs. The strategy also ignores the cost and land requirement of eventually having to land apply the accumulated sludge.

A strategy of maintaining maximum nutrient value of manure and then applying it so that no nutrient is wasted can produce a lower per acre value, but it has a greater total value because more acres benefit (upper right of Table 4). If the cost of this strategy is equal to or less than the "cost minimizing" strategy discussed earlier, maximizing nutrient value clearly would be preferred. Even more optimistically, if the total value of the nutrients exceeds the total cost of utilizing them, manure ceases to be a waste and becomes a positive resource. Our simulations suggest that this is quite possible.

A particular set of background circumstances; i.e., soil type, crops grown, crop and fertilizer prices, size of operation, etc. are held constant in the several scenarios presented in Table 4, while the scenarios differ in terms of alternative land application strategies balancing economics and regulatory compliance. Dramatic differences seen in land requirements and fertilizer value suggest that strategy choice is critical. Furthermore, application cost estimates based on volume of manure applied indicate that choices result in a range of net impacts (from net losses for the "cost minimizing" strategies to net gains for a number of the other, more nutrient-conserving strategies). So while these results are circumstantial, they do suggest that strategies that are more conserving of manure nutrients may benefit producers.

Improving the economics of manure management might involve more careful balancing of footprint size against application cost. Application cost estimates used in our planning exercise are independent of footprint size (at the scale of the example). This is likely to change if applicators suddenly must cover several times more area to apply the same volume of manure. However, a strategy that might provide a practical compromise is one in which the total area of the footprint is determined by phosphorus or potassium; while only a portion of that area is used for application in a given year. In such a strategy, the annual application rate could be determined by the more leachable nitrogen. The application rate would over-apply phosphorus and potassium, but the particular acreage would not be revisited until those excess nutrients are consumed. Such a strategy would enable a producer to more fully recycle manure nutrients, while minimizing operational cost of manure application.

Other implications

In addition to economic considerations, there are a number of other issues important to manure management. Some of these issues reflect changes in attitude within the swine industry, others reflect changes in society's view of the industry.

Phosphorus limit. Increasingly nitrogen is not the controlling nutrient in determining needed land application area. Land applying according to a nitrogen limit over-applies phosphorus (Roka and Hoag 1996, and Sweeten 1998). This is most obvious when applying lagoon effluent (Table 5). In some regions of the US, several years of applying by a nitrogen standard has created areas of high phosphorus levels in soil and has increased regulatory concerns (Miner

1999). If regulations continue to evolve to replace nitrogen limits with sustainable phosphorus rates, a number of the management strategies discussed here will no longer be viable alternatives.

Lagoon disfavor. Apart from concerns about nutrient management, anaerobic lagoons are being viewed with increasing disfavor. Concerns about lagoon wall integrity and leakage have increased regulatory oversight and permit requirements (510 ILCS 77/1 *et seq.*). In North Carolina, Smithfield Foods recently agreed to replace lagoons on 276 of their farms with "environmentally superior systems" and to provide financial assistance to any of their contract growers following suit (www.hogwatch.org/resourcecenter/smithfieldagree/smithfieldagree.html). If anaerobic lagoon systems continue in disfavor, the range of viable storage alternatives will decrease. In the absence of anaerobic lagoons, or some other pre-treatment technology, even producers applying manure according to a nitrogen limit will require more acres, there will be less over-application of phosphorus and potassium, and more of the total nutrient value of the manure will be realized.

Sludge disposal and lagoon decommissioning. Regulations require that lagoon sludge, plus a specified depth of soil from the bottom and sides of a lagoon, be land applied at agronomic rates at the time a lagoon is decommissioned (35 IAC 506). A simple calculation based on conservation of mass indicates that enough phosphorus and potassium accumulates in sludge each year to require 119 and 65 acres for land application respectively. Allowing this material to accumulate, reduces the land required for annual application. However, it is shortsighted because it ignores the eventual land requirement and expense of decommissioning.

Scale effects. Boland *et al.* (1999), and Roka and Hoag (1996) reported that while costs of handling and land applying swine manure exceed benefits, there are economies of scale in minimizing costs. In both studies, minimum cost manure management systems employed an anaerobic lagoon and land applied using irrigation. This technology can be engineered to move large amounts of lagoon effluent using pumps and pipelines with low labor and operation costs. The systems are expensive to set up, but once the investment is made, the cost per unit volume of manure applied drops as the scale of the swine facility increases.

A similar pattern of declining costs with increasing scale was found in bids obtained by survey in early 2000 from independent waste handling businesses operating in Illinois. It is important to note that some of the application technologies ("haul and spread" and "irrigate" in Figure 1)

leave the manure on the ground surface. Not performing soil incorporation provides much of the apparent cost advantages of these application options.

Concentration within the swine industry

A sustainable agriculture imperative is to close the nutrient cycle, as much as possible – from soil, to crops, to animals, and back to soil. The *footprint* concept actualizes this imperative and our analysis demonstrates that it implies limits to geographic concentration of hog production.

Our analysis further suggests that accomplishing this may not be the financial burden on producers that conventional wisdom has suggested.

REFERENCES

35 IAC 560. 1976. Illinois Administrative Code. Title 35: Environmental Protection. Subtitle E: Agriculture Related Water Pollution. Chapter II: Environmental Protection Agency. Part 560: *Design Criteria for Field Application of Livestock Waste.*

510 ILCS 77/1 *et seq.* 1999. Illinois Compiled Statutes. Chapter 510: Animals. Act 77: *Livestock Management Facilities Act.* Sections 77/1 *et seq.*

Boland, M.A., K.A. Foster, P.V.Preckel, D.D. Jones and B.C Joern. 1999. Using Linear Programming to Minimize Manure Storage and Application Costs in Pork Production. *Journal of Production Agriculture.* Vol 12 (Jul) pp. 405-408.

Gollehon, N. and M. Caswell. 2000. Confined Animal Production Poses Manure Management Problems. *Agricultural Outlook/ September 2000.* Economic Research Service, USDA. pp.12-18.

Hoag, D.L. and F.M. Roka. 1995. Environmental Policy and Swine Management: Waste Not or Want Not? *American Journal of Alternative Agriculture.* Vol 10 (Fall) pp. 163-166.

Illinois Agronomy Handbook: 1999-2000. 1998. University of Illinois at Urbana-Champaign. College of Agricultural, Consumer and Environmental Sciences. Department of Crop Sciences and University of Illinois Extension.

Jackson, L.L., D.R. Keeney and E.M. Gilbert. Swine Manure Management Plans in North-Central Iowa: Nutrient Loading and Policy Implications. *Journal of Soil and Water Conservation.* Vol 55(2nd Quarter) pp. 205-212.

Midwest Plan Service. 1993. *Livestock Waste Facilities Handbook, MWPS - 18.* Ames: Iowa State University Press.

Miner, J.R. 1999. Alternatives to Minimize the Environmental Impact of Large Swine Production Units. *Journal of Animal Science.* Vol 77(Feb) pp. 440-444.

Overcash, M.R., F.J. Humenik and J.R. Miner. 1983. *Livestock Waste Management, Vol. I.* CRC Press, Inc. Boca Raton, FL. pp. 200-214.

Roka, F.M. and D.L. Hoag. 1996. Manure Value and Liveweight Swine Decisions. *Journal of Agricultural and Applied Economics.* Vol 28(Jul) pp. 193-202.

Sweeten, J.M. 1998. Separation Distances for Swine Odor Control in Relation to Manure Nutrient Balances. *Applied Engineering in Agriculture.* Vol 14(Sep) pp. 543-549.

Young, C.E., M.B. Crowder, J.S. Shortle, and J.R. Alwang. 1985. Nutrient management on dairy farms in southeastern Pennsylvania. *Journal of Soil and Water Conservation.* Vol 40 (Sep-Oct) pp. 443-445.

Table 1: Nutrient Content of Swine Manure (lbs/day)*

Animal Size	Total N	P_2O_5	K_2O
65 lbs	0.030	0.022	0.023
150 lbs	0.070	0.050	0.054
200 lbs	0.090	0.067	0.072
250 lbs	0.115	0.085	0.089

* From *Livestock Waste Facilities Handbook*, MWPS 18

Table 2: Lbs of Nutrient per Facility Space per Day (150 lb animal)*

Nutrient	Feces	Pit	Lagoon
Total N	0.0676	0.0638	0.0188
P_2O_5	0.0510	0.0405	0.0225
K_2O	0.0540	0.0510	0.0413

* Based on 35 IAC 560, *Design Criteria for Field Application of Livestock Waste*, Table 1 and Table 2.

Table 3: Annual Manure (Fertilizer) Application Rates

	NO_3 (lb/ac)		P_2O_5 (lb/ac)		K_2O (lb/ac)	
	Agronomy Hndbk[1]	Illinois Regs.[2]	Agronomy Hndbk[1]	Illinois Regs.[2]	Agronomy Hndbk[1]	Illinois Regs.[2]
Corn (per bu)	1.20	1.30	0.43	0.55	0.28	0.28
Soybeans (per bu)	0.00	1.30[3]	0.85	1.10	1.30	2.40

[1]From *Illinois Agronomy Handbook*, 1997 - 1998, pgs. 92 and 106.
[2]From 35 IAC 560, *Design Criteria for Field Application of Livestock Waste.*
[3]Regulations allow the assumption that legumes scavenge applied nitrogen in preference to fixing it from the atmosphere and, therefore, take up as much nitrogen on a per acre basis as does corn in the same rotation.

Table 4: Value of Nutrients in Manure and Area of Cropland Required for Land Application of Annual Manure Produced from a 1,000 Head Finishing Facility.

Method of Storage		Regulatory Limits[1]			Agronomy Handbook[2]		
		Scavenging[3]	No Scavenging		No Scavenging		
		N Limit[4]	N Limit[4]	P Limit[4]	N Limit[4]	P Limit[4]	K Limit[4]
Pit	Footprint	100 ac	200 ac	212 ac	217 ac	273 ac	343 ac
	$/acre	$36.19	$36.19	$43.50	$36.19	$32.52	$27.36
	Fert. Val.	$3,623	$7,246	$7,675	$7,850	$8,862	$9,391
	NER[5]	$-1,677	$1,946	$2,375	$2,550	$3,562	$4,091
Anaerobic Lagoon	Footprint	30 ac	59 ac	118 ac	64 ac	151 ac	278 ac
	$/acre	$44.59	$44.59	$34.86	$36.19	$25.79	$17.46
	Fert. Val	$1,068	$2,135	$3,294	$2,313	$3,905	$4,852
	NER[5]	$-4,807	$-3,740	$-2,581	$-3,562	$-1,970	$-1,023

1. Regulatory Limits are based on specifications from *Design Criteria for Field Application of Livestock Waste*, from IEPA.
2. Crop use of nutrients values are taken from *U of I Agronomy Handbook.*
3. Crop use rates assume soybeans scavenge nitrogen from the soil before they will fix it from the atmosphere, therefore soybeans "recycle" as much nitrogen as corn.
4. Each scenario is characterized by the macro-nutrient that limits the rate of application.
5. Net Economic Result from Equation (6).

Table 5: Excess Nutrients Applied (lbs/ac/yr) in Various Land-Application Scenarios.

Method of storage		Regulatory Limits[1]			Agronomy Handbook[2]		
		Scavenging[3]	W/o Scavenging		W/o Scavenging		
		N limit[4]	N limit[4]	P limit[4]	N limit[4]	P limit[4]	K limit[4]
Pit	Excess N	15.0	7.5	2.1	0	0	0
	Excess P	92.1	19.3	15.3	13.7	0	0
	Excess K	129.9	38.2	33.1	31.1	13.9	0
Anaerobic Lagoon	Excess N	15.0	7.5	0	0	0	0
	Excess P	221.1	83.8	15.3	73.2	0	0
	Excess K	450.5	198.5	72.7	179.1	44.7	0

1. Regulatory Limits are based on specifications from *Design Criteria for Field Application of Livestock Waste*, from IEPA.
2. Crop use of nutrients values are taken from *U of I Agronomy Handbook*.
3. Crop use rates assume soybeans scavenge nitrogen from the soil before they will fix it from the atmosphere, therefore soybeans "recycle" as much nitrogen as corn.
4. Each scenario is characterized by the macro-nutrient that limits the rate of application.

Table 6: Number of Years Before Phosphorus in the Soil Exceeds Regulatory Limit.

Form of manure	Regulatory Limits[1]			Agronomy Handbook[2]		
	Scavenging[3]	W/o Scavenging		W/o Scavenging		
	N limit[4]	N limit[4]	P limit[4]	N limit[4]	P limit[4]	K limit[4]
Pit Storage	24	118	147	164	∞	∞
Anaerobic Lagoon	10	27	147	31	∞	∞

1. Regulatory Limits are based on specifications from *Design Criteria for Field Application of Livestock Waste*, from IEPA.
2. Crop use of nutrients values are taken from *U of I Agronomy Handbook*.
3. Crop use rates assume soybeans scavenge nitrogen from the soil before they will fix it from the atmosphere, therefore soybeans "recycle" as much nitrogen as corn.
4. Each scenario is characterized by the macro-nutrient that limits the rate of application.

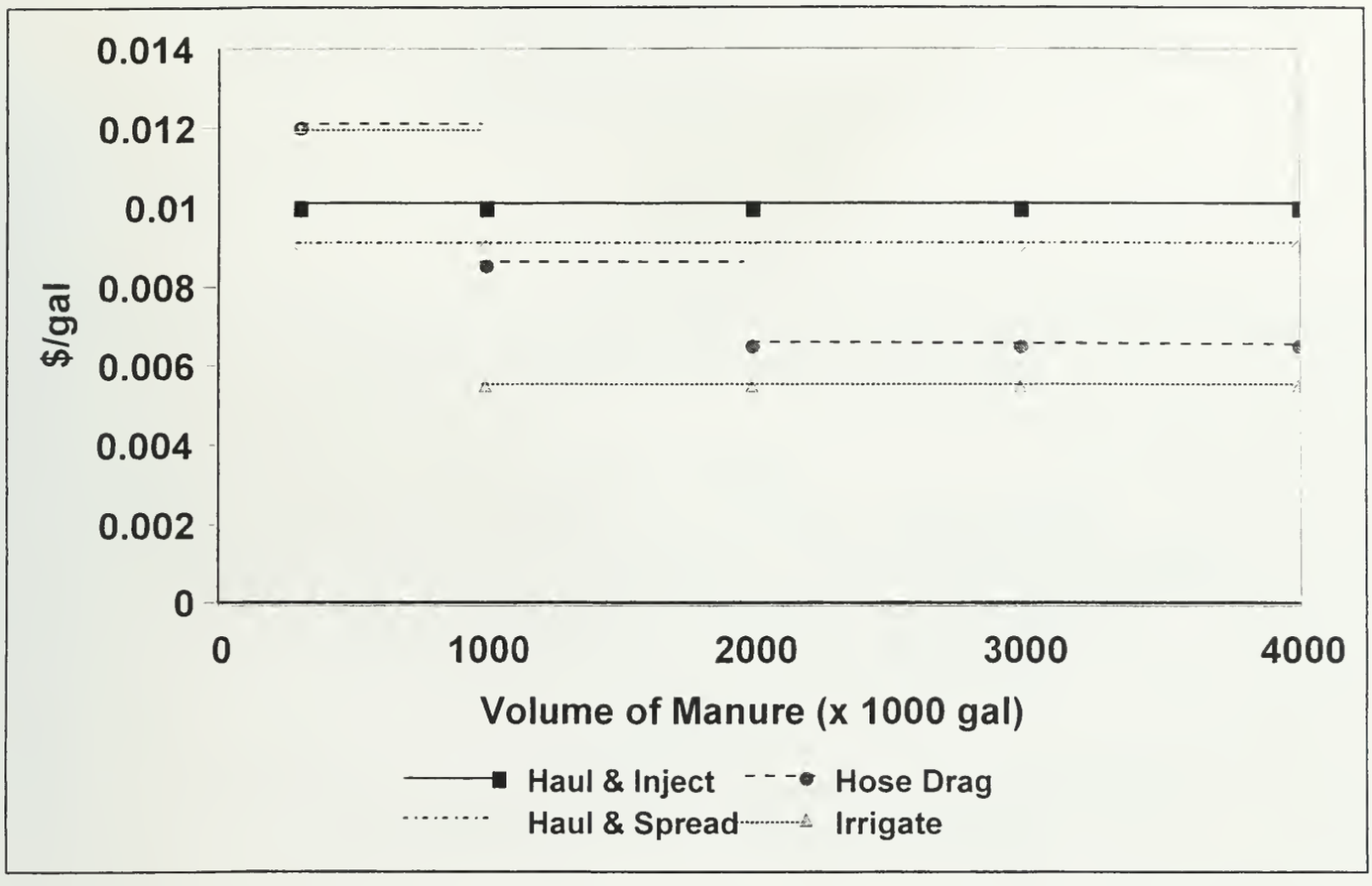

Figure 1: Manure Application Costs

Economic Impact of Nutritional Strategies to Decrease Nutrient Excretion from Batch Swine Production Facilities; A System Dynamics Approach

by

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This study was funded in part by a grant from the Council for Food and Agricultural Research, Swine Odor and Manure Management SRI.

ABSTRACT

A system dynamics model of pig growth and associated farm level economic impact is developed to evaluate the economic feasibility of three nutritional approaches (phase feeding, avoiding over-formulation, and more accurate estimate of nutrient requirements) to reduce nutrient excretion. The strategies are evaluated in terms of ARC elasticity of nutrient excretion with respect to profit. Model simulations suggest that more accurate nutrient requirement estimations may be a more profitable way than the other approaches evaluated to reduce nutrient excretion from swine producing facilities.

INTRODUCTION

Changes in the size distribution of hog production operations have been well documented in the literature [17, 28]. In a recent survey, Lawrence, Grimes, and Hayenga [22] reported a dramatic increase in the number of hog production operations that produce over 50,000 head a year. Their

survey revealed that 145 firms in this class (over 50,000 head a year) marketed about 33.1 million head (37% of US produced) in 1997, which is a sharp increase from 66 firms producing 16 million pigs in 1994. Changes in the structure of the industry have been accompanied by equally dramatic increase in the size of swine operations. This trend has raised environmental concerns.

Abdalla and Mo [1] discussed the possible effect of environmental regulation on the expansion of the pork industry and manure/nutrient management strategies have been modeled and discussed [29, 13, 12]. More recently, Innes [18] laid a comprehensive theoretical foundation for the economics of the manure management problem. Even though these approaches are internally consistent and valid, the models could be more complete if they considered nutritional approaches to nutrient management, because excess nutrient excretion might be effectively prevented by taking nutritional approach.

Swine nutritionists have recognized that excess nutrient excretion occurs and they have proposed various approaches to reduce nutrient excretion. Kornegay and Harper [20] surveyed the associated literature and reported 8 strategies to reduce nutrient excretion from swine production facilities. They are 1) improved feed efficiency 2) more accurate estimation of nutrient requirements 3) avoiding over-formulation 4) feeding for optimal, not maximum performance 5) use of crystalline amino acids and high quality protein 6) improving phosphorous availability 7) phase feeding 8) reduced feed waste. However, the evaluation on the economic feasibility of these strategies is yet to be completed.

Using cost-benefit analysis, Boland, Preckel, and Foster [4] evaluated two phosphorous reduction strategies: 1) using synthetic amino acid, and 2) using phytase to improve phosphorus availability. Boland, Foster, and Preckel [3] discussed the over-feeding problem in animal diets and discussed the possible impact of excess nutrients on manure nutrient excretion.

The use of dynamic modeling in solving problems of this style has natural appeal. It does require some level of mathematical skill that has prevented this modeling technique from being used widely. However, empowered by modern computing, users in different disciplines can collaborate and integrate their efforts without having to deal with systems of differential equations.[1]

System dynamics have been widely used in modeling natural phenomena [15], dynamic economic systems [30], and the environment [14]. Specifically, a systems dynamic approach is well fitted to animal growth modeling, in which many variables heavily depend on time. Technically, system dynamics numerically approaches dynamic problems based on difference equation. In the economics literature of swine production, however, most growth models are differential equation based [8, 5], facilitating the use of optimization techniques. A comprehensive theoretical discussion of models of this kind is provided in Parks [27]. The major advantage of this approach is its mathematical clarity and technical convenience in optimization.

One potential limitation of mathematical models is that a set of differential equation may not be sophisticated enough to explain the interrelated physiology of swine growth that is affected by many variables. Even though it is possible to consider all the relevant variables in differential

equation form, there is still a problem of tractability of the model. Once a model of this kind is created, it may be plagued by technically undesirable conditions such as specific functional forms, or discontinuity of functions. Systems dynamic approaches allow many differential equation problems to be translated into difference equation problems by taking advantage of the numerical approaches of specific computer programs. Also, computer software developed for system dynamics help the integrity of the model hold, when otherwise overwhelming nonlinear or discontinuous details are integrated.

The purpose of our paper is to evaluate the economic impact of three nutrient reduction strategies among the eight nutrient reduction strategies surveyed in Kornegay and Harper [20] using the system dynamics approach. The three strategies examined were: 1) phase feeding, 2) avoiding over formulation of the diet, and 3) more accurate estimate nutrient requirements.

Model Description

A systems dynamics approach was used to model a hypothetical swine finishing operation of 1020 head.[2] The model consists of three sub-models: growth, excretion, and economics. The model suggested by the National Research Council [26] and the feed intake prediction equations [24] were used to build the animal growth component of our model. A linear model is used to build the excretion component because available data on digestibility and retainability of nutrients suggest linear relationships. The economic model developed was adapted [23, 31] into a dynamic framework. In the following sections, the models will be briefly presented. Complete presentation of the model can be found in the appendix.

Schematic presentation and assumptions of the models

The growth model is comprised of three major components: energy requirements, feed intake estimation, and body weight (Figure 1). Daily feed intake is governed by energy requirements and influenced by other factors such as pig density (or space allowance), environmental temperature, antibiotics, energy concentration in feeds, and feed type (pellet vs meal). Daily energy requirement is determined by body weight, and influenced by other factors such as genotype, sex, environment and digestible energy content in feeds. Body weight changes over time are determined by an assumed daily body weight gain with an assumed distribution. The excretion of nutrients is estimated using the digestibility and retainability of nutrients (Figure 2). Thus, when the amount of feed consumed and the specific diet formulations are known, daily nutrient excretion (in the form of feces and urine), and daily nutrient retention in the body can be estimated. Digestibility and retainability from Kornegay and Harper [20] are used.

The economic submodel [23,31] calculates the profit associated with the biological model outlined by Figures 1 and 2. The biological models are developed for an individual pig. However, to apply the live weight based penalty pricing system, a finishing barn with 1020 head with an associated distribution of pig weights is assumed [23,31]. Feed cost is estimated from the feed consumed (from the nutrient excretion component) and a weighted average feed price. Other fixed and variable costs are assumed. A full description of the three submodels is presented in the appendix.

The growth submodel is linked to the excretion submodel through daily feed intake. Also, body weight is linked to the economic submodel, where the body weight is converted into a distribution of pig weights assuming a standard deviation.

Pricing systems are important in modern hog marketing [21]. Pricing based on live-weight is traditional. [5][3] Also, growth models relate to live weight produced. Thus, a live-weight based pricing system is assumed. A step function is assumed using a pricing matrix.[4]

It is assumed that diet manipulation over the range considered for our study will not affect the performance (weight gain) of pigs. That is, the concept of environmentally friendly nutritional manipulations is to formulate cost-effective diets and feed minimum mineral requirement for acceptable performance [20]. For example, crystalline amino acids can reduce N excretion without affecting performance [1, 16, 19, 32]. Lastly, it is assumed that swine producers ship pigs when profit is maximized. That is, the model is run to estimate the optimal shipping schedules that maximize profits (Figure 3a) and the optimal shipping dates then feedback to estimate the nutrient excretion (Figure 3b).

Nutrient Reduction Strategies Evaluated

National Research Council [26] surveyed strategies to reduce nutrient excretion, and the detailed strategies are reported in Kornegay and Harper [20]. Among 8 strategies suggested, 3 strategies are expected to be readily practical and are evaluated here. They are: phase feeding, low-protein diet (avoiding over-formulation), and more accurate estimates of animal nutrient requirements.

Nutrient requirements of pigs change with growth. If one fixed diet (single phase) is used, inefficiencies occur. Inefficiency of single phase feeding compared with 4 phase feeding is illustrated (Figure 4; adapted from Kornegay and Harper [20]). Examining Figure 4, three major control variables can be identified to minimize inefficiency (represented by the summation of the shaded areas). They are number of phases, the length of each phase period, and the dietary crude protein (CP) for each phase. Inefficiencies in feeding (represented by areas of CP shortage or excess) can be reduced by employing different diet formulations as the CP requirement changes. In the literature, reduction of N excretion is reported [16, 7] when multiphase feeding is used. However, to highlight the effect of the number of phases, it is assumed that the other two control variables follow nutritionist recommendations. Partitions of weight are assumed to be 20 kg to 34 kg, 34 kg to 63.5 kg and 63.5 kg to 110 kg for 3-phase feeding.[5] CP assumed for these phases (from the assumed diet formulation) are 14.53 %, 13.75 %, and 12.35 % (Table 1).[6]

Avoiding over-formulation (feeding above required levels) of diets can reduce nutrient excretion. Over-feeding of phosphorous (P) may be a common practice [10]. Thus, simply lowering P in the diet, can reduce P excretion. Also, supplementing with specific amino acids reduces excess dietary CP and the amount of N (nitrogen) excretion. In our analysis, we compare a low CP diet with two higher CP diets (diet numbers 8, 9 and 1 [9]). Detailed levels of CP are presented in Table II.

More accurate estimates of nutrient requirements can lead to reduced nutrient excretion. That is, if the standard used by industry is too high then followers of the industry standard may be over-feeding nutrients. Cromwell [10] reported significant differences in nutrient requirement standards between NRC [25] and industry. Assumptions are detailed in Table III. All diet formulations used for our simulation are presented in Table IV.

Lastly, we calculate ARC elasticity of nutrient excretion with respect to profits because we need to establish a common ground in evaluating the performance of different strategies. Thus, the % change in nutrient excretion with respect to the % change in profit of different strategies will be reported.

Simulation Results

Two indicators of performance (nutrient excretion and profitability) are tracked and reported (Figure 5). Using these indicators, ARC elasticity of nutrient excretion with respect to profit are reported (Table V). Moving from a 1-phase diet to a 2-phase diet, profit decreased by 1% to reduce N excretion by 4.71%. Thus, 2-phase feeding does not improve profits over a single finishing diet. However, if 3-phase feeding is used, for a 1% increase in profit, N excretion will be reduced by 0.73%. This is a win-win situation. Producer profits increase while simultaneously decreasing the amount of N excretion, thus limiting the potential impact on the environment.

Feeding diets with lower CP is also an effective strategy to reduce nutrient excretion and improve profitability. That is, if a medium CP diet is compared against a high CP diet, N excretion will decrease by 1.02% while profits increase by 1% (Table V). Additionally, lowering CP further still leads to additional reduction of N excretion and gain in profits. If the medium CP diet is compared against the low CP diet (Table II), N excretion will decrease by 0.58% while profits increase by 1% (Table V), demonstrating a decreasing rate of the effectiveness of the lower CP diet strategy.

Complying with university standards of nutrient requirements rather than industry standards can significantly reduce nutrient excretion. P excretion can be decreased by 2.18%, while still increasing profit by 1% (Table V), if university standard is followed. P reduction is largest if the NRC standard is adopted (2.41% reduction in P excretion while gaining 1% in profit). Thus, if only one strategy is to be employed, estimating more accurate nutrient requirements may be the most effective strategy to decrease P excretion.

Discussion and Model Weaknesses

Commercial fertilizer application is a major source of nutrient presence in most agricultural areas. However, fertilizer use in crop production does not frequently lead to conflicts and lawsuits because of its implications as a non-point source of pollution. In contrast, swine production facilities are visible and sometimes odorous, leading to public scrutiny and conflict over pork facilities. Therefore, it is essential to the survival of the swine industry to demonstrate

that they follow environmentally friendly management by employing nutritional strategies to reduce nutrient excretion.

In this paper, some of the nutritional strategies to reduce nutrient excretion are evaluated for economic feasibility. Each strategy targets on a specific nutrient excretion reduction. Thus, phase feeding and avoiding over-formulation focus on reduction of nitrogen excretion, but meeting more accurate requirement focuses on phosphorous excretion reduction.

Initial simulations carried out with the model developed and evaluated suggest that it is also profitable for producers to follow environmentally friendly management. Thus, there is no conflict of interest for pork producers in improving their environmental stewardship by using any of the 3 strategies evaluated here. However, further research aimed at validating the assumptions used in this model is required to confirm these results.

Expansion of the model can approach the environmental problem of large swine finishing operations in a more systematic way by integrating manure handling systems such as deep-pit and lagoon. This is an avenue for future studies.

Other than nutrient output issues associated with swine operations, air quality (odor) in areas surrounding pork production facilities could be modeled. The amount of nutrients in manure is just one variable in the integrated models of air dispersion and odor recognition (by human). Although it is an important issue to tackle, additional collaboration from engineers and physiologists are needed.

Revenue estimated by this model is higher than would be expected in a real production system. In the model, pig deaths and marketing of non-standard market pig are not considered. However, diet manipulation in the analysis range of our investigations should not affect the mortality rate or the proportion of non-standard pigs substantially. Our main analyses and results are based on relative changes of profit and nutrient excretion. Therefore, the implications of our main results are still valid. Also, alternative types of pricing system (such as carcass lean content based pricing system) could be modeled even though it is unlikely to bias the relative result of the model simulation.

The results of this study suggest that effects to develop more accurate estimates of the animal nutrient requirements and of the nutrient composition of feedstuffs are likely to result in cost-effective reductions in nutrient output from swine finishing operations.

Figure 1 : Schematic Presentation of the Growth Submodel

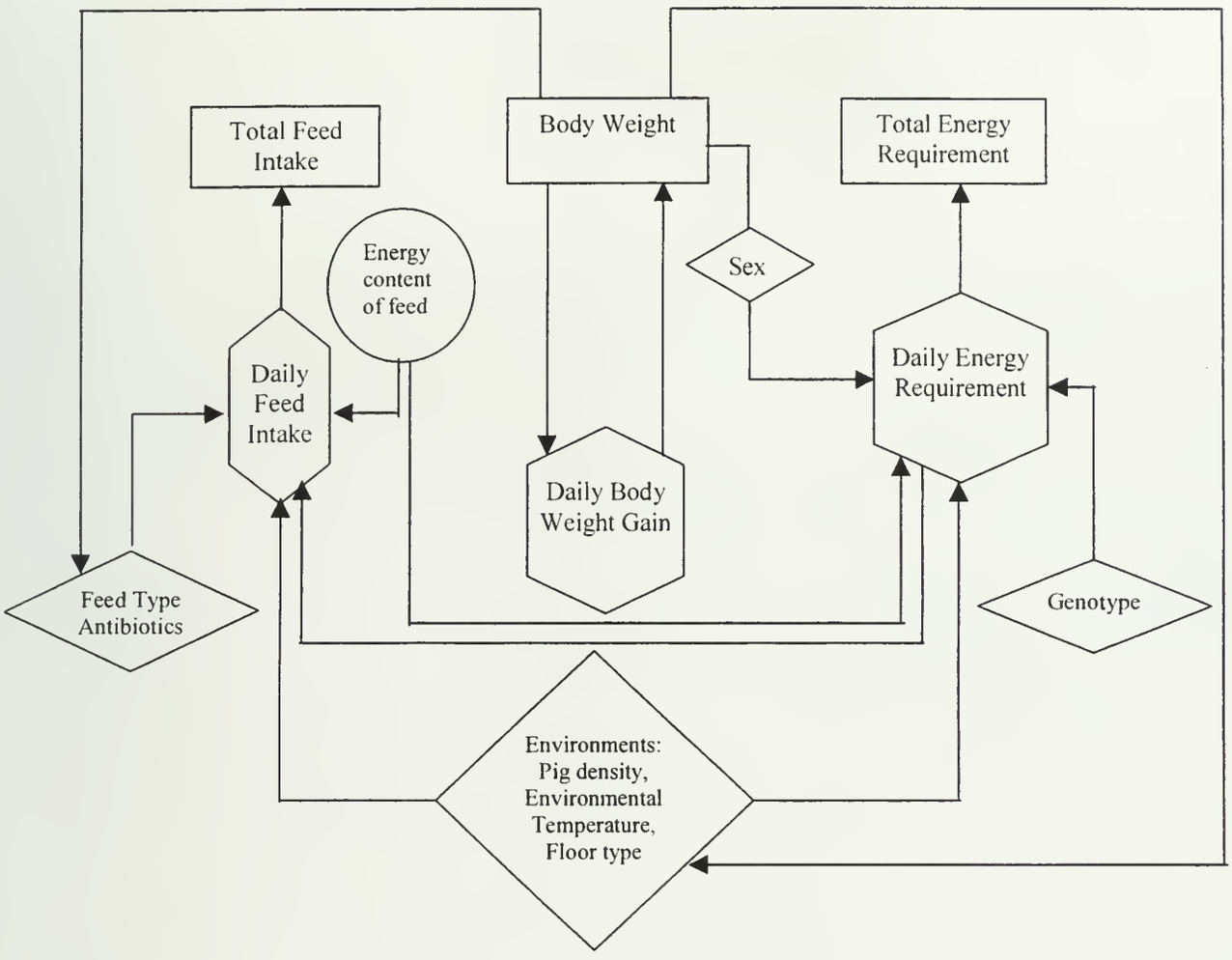


Figure 2 : Schematic Presentation of Excretion Submodel

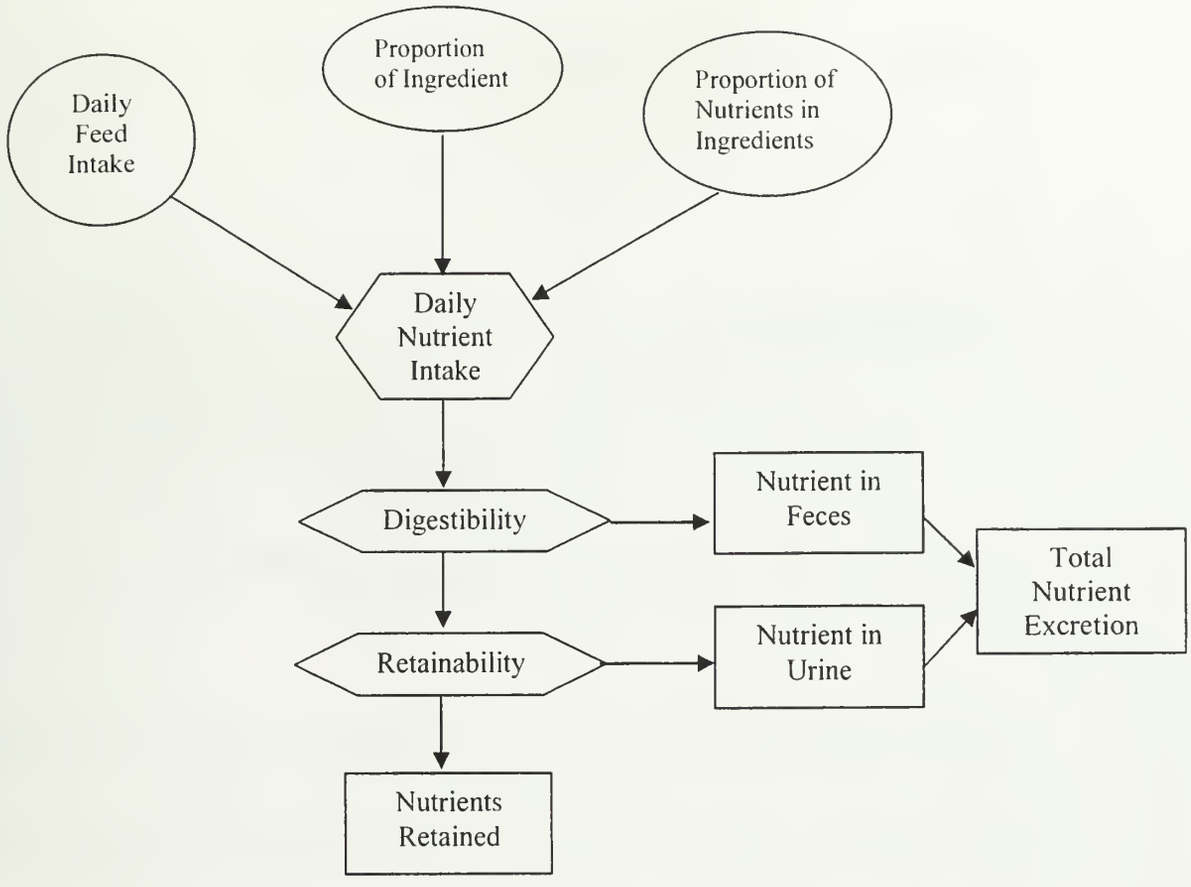
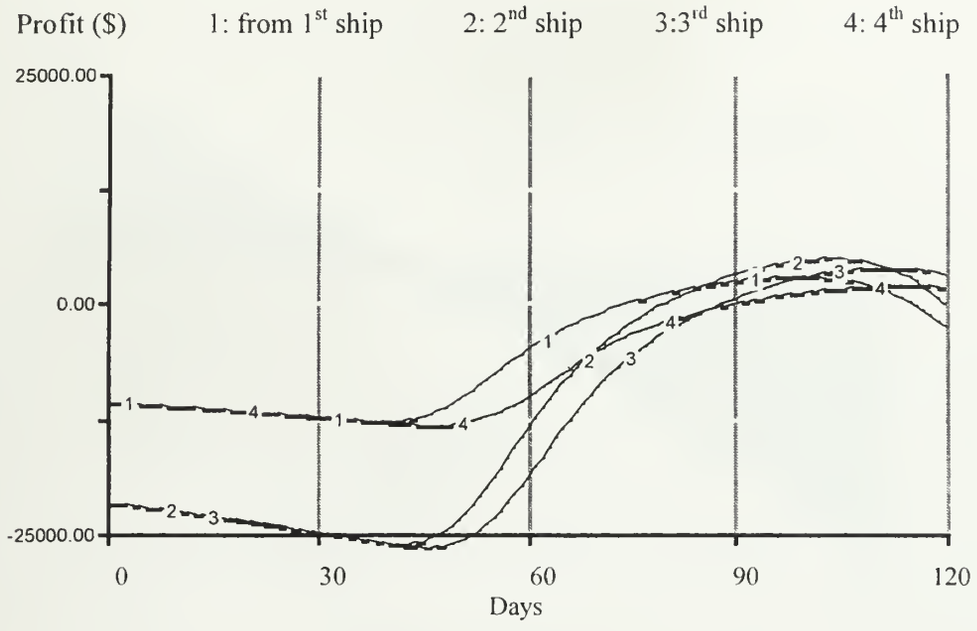


Figure 3 : Simulation Result of Economic Submodel

3a) Shipping Schedule and Revenue minus Costs from Four Shipments from One batch



3b) Cumulative Nutrient Amount (kg) Excreted from 1020 Head Finisher Barn

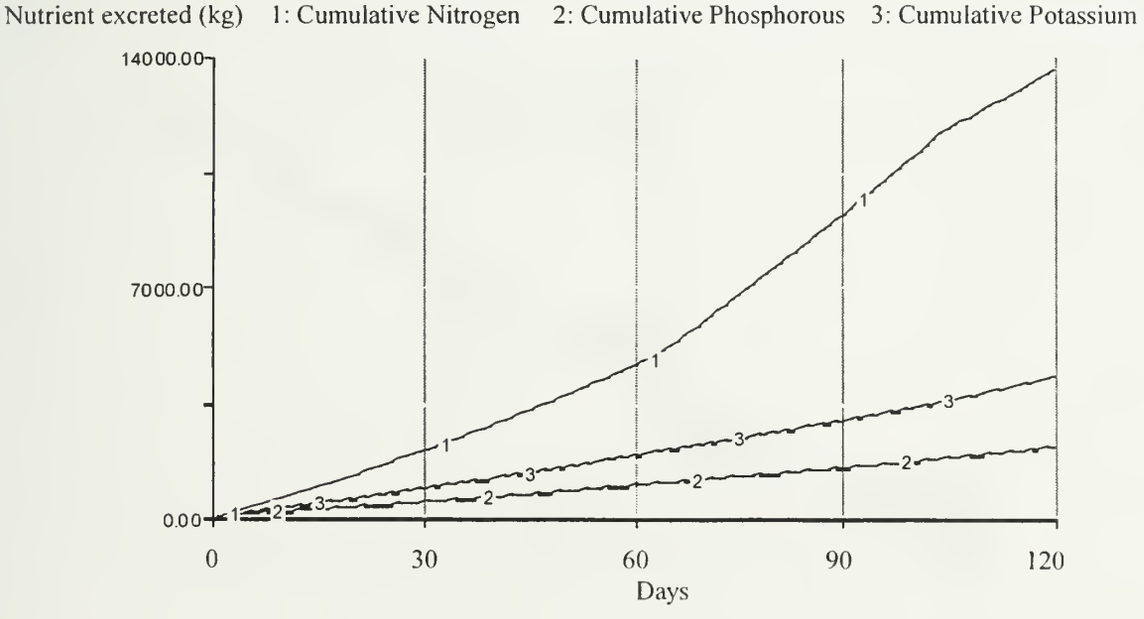


Figure 4 Illustration of Multiphase Feeding : Adapted from Kornegay and Harper [20]

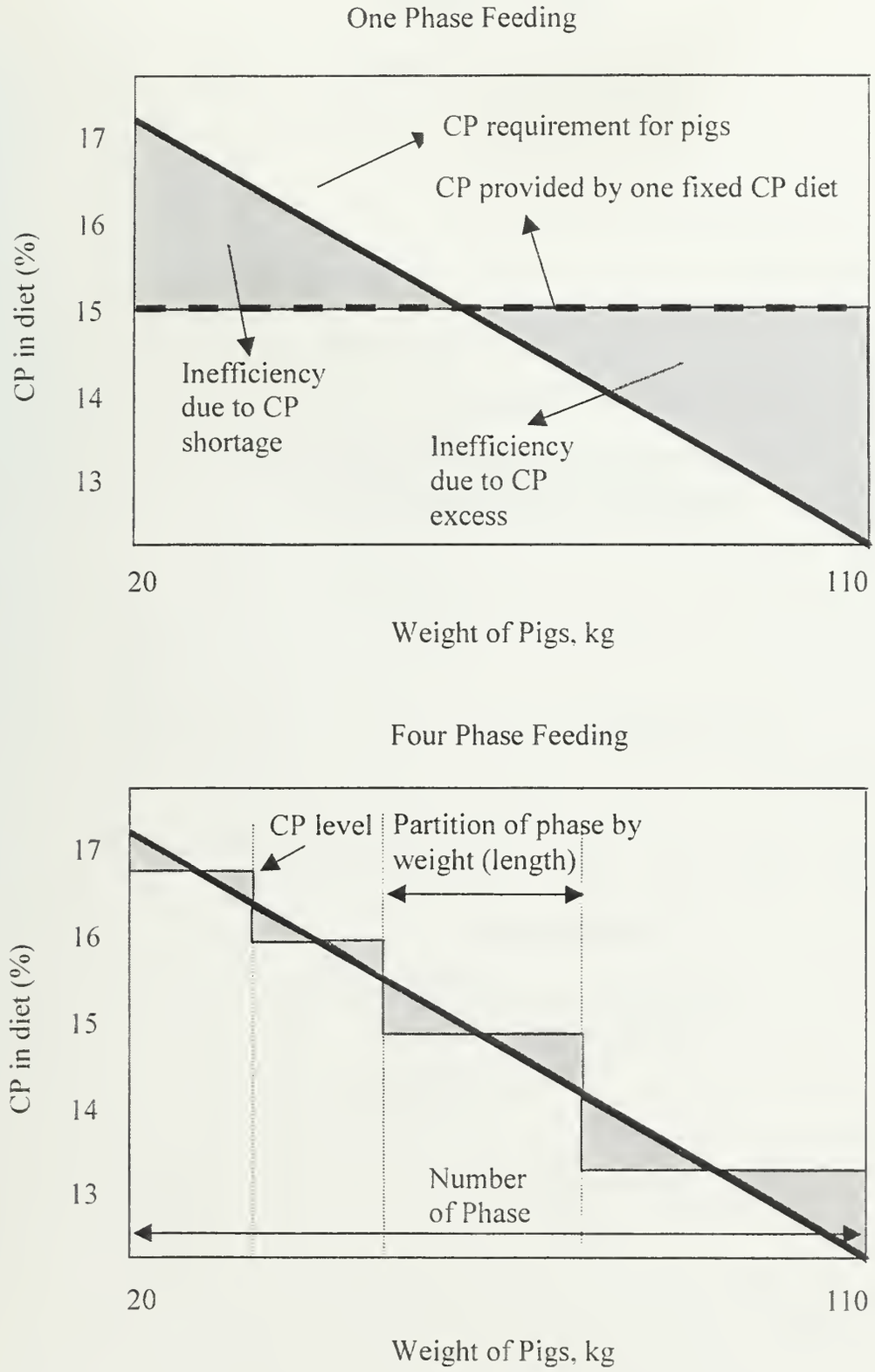
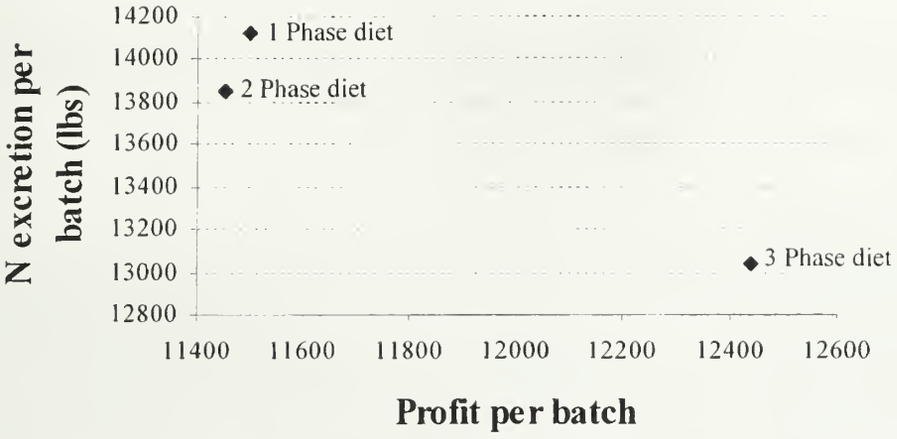
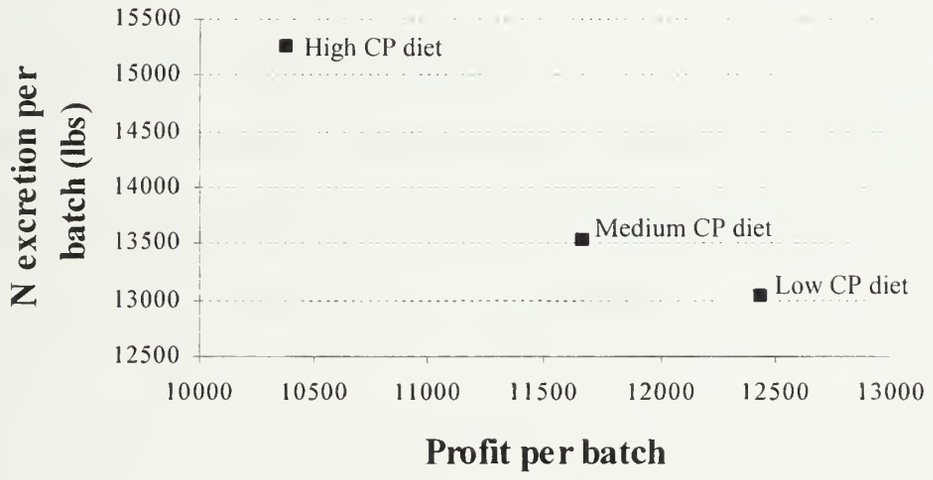


Figure 5 :

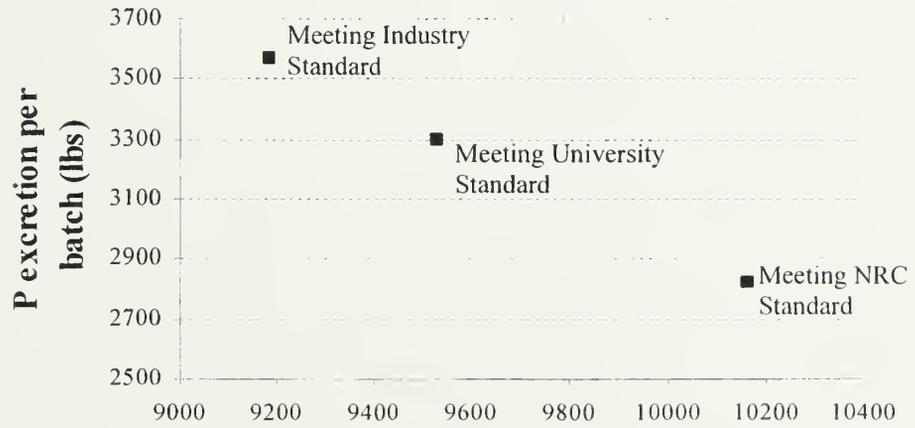
5a) Profit per batch and N excretion (Phase Feeding)



5b) Profit per batch and N excretion (Over-formulation of CP in diet)



5c) Profit per batch and P excretion (Accurate Requirement)



N = Nitrogen, P = Phosphorous, CP = Crude Protein

Table I : Assumptions for Phase-Feeding Evaluation

Number of Phases	1	2	3
Partition of phase by weight	20 to 110 kg	20 to 65 kg[c] 65 to 110 kg	20 to 34 kg[a] 34 to 63.5 kg 63.5 to 110 kg
CP level assumed	13.54 %[e]	14.14 %[d] 13.05 %	14.53 %[b] 13.75 % 12.35 %

a. Weight ranges are from CES [9].

b. Based on diet number 8 [9], CP is calculated

c. The midpoint (of 20 and 110) is taken to break the range into two equal weight gain parts.

d. Averages of CP (14.53 and 13.75; 13.75 and 12.35) are assumed.

e. Average of CP (14.53, 13.75, and 12.35) are assumed.

Table II : Assumption for Over-formulation

Number of Phases	1	2	3
CP of diet 8 (%): Low CP	14.53[a]	13.75	12.35
CP of diet 9 (%): Med. CP	15.26	14.14	12.49
CP of diet 1 (%): High CP	16.80	15.81	13.80

a. In CES [9], the CP of diet 8 for 1st phase is reported as 15.30%. As explained in footnote 6, the CP reported here is lower.

Table III : Assumption for Accurate Nutrient Requirement Model Simulation: P requirement based on the Survey by Cromwell [10]

	NRC (%)	Universities (%)	Industry (%)
20 to 50 kg[a]	0.50[b]	0.54	0.60
50 to 100 kg	0.40	0.49	0.52

a. The default diet formulation of the model has 3 phases (20 to 34kg, 34 to 63.5kg, and over 63.5 kg), which needs to be converted into 2 phases (20 to 50kg and 50 to 100kg). In the two phase model, it is assumed that the growth is the average of phase 1 and 2 from the 3 phase model, and the growth for the 2nd phase is the average of phase 2 and 3 from the 3 phase model.

b. To meet the requirements, diet formulations are manipulated. In doing so, only the % of dicalcium phosphate and the % of corn are changed to meet requirements. Other premix ingredients are assumed fixed; manipulating soybean meal would alter CP, which would violate the assumption of *ceteris paribus*.

Table IV : Diet Formulation used for analyses (% of each ingredient).

4a) Phase Feeding (Default: Diet #8, 3-phase in UIUC CES)

Ingredient	1-phase	2-phase		3-phase		
Corn, Yellow	81.91	80.25	83.28	79.15	81.60	85.70
Soybean Meal 48% (SBM)	15.07	16.75	13.70	17.85	15.60	11.75
Di-calcium Phosphate (Dical)	1.55	1.55	1.55	1.55	1.35	1.15
Calcium Carbonate (Limestone)	0.80	0.80	0.80	0.80	0.80	0.80
Trace mineral salt (TMS)	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin mix (Vit Mix)	0.15	0.15	0.15	0.15	0.15	0.15
Lysine	0.15	0.15	0.15	0.15	0.15	0.10
Phytase	0.00	0.00	0.00	0.00	0.00	0.00

4b) Over-formulation

	Diet # 1 (High CP)			Diet # 9 (Med. CP)			Diet # 8 (Low CP)		
Phase	1	2	3	1	2	3	1	2	3
Corn	72.70	75.70	81.55	75.85	79.55	84.85	79.15	81.60	85.70
SBM[a]	24.60	21.75	16.05	21.20	17.65	12.60	17.85	15.60	11.75
Di-cal	1.45	1.25	1.10	1.55	1.35	1.15	1.55	1.35	1.15
Limestone	0.75	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
TMS	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vit Mix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Lysine	0.00	0.00	0.00	0.10	0.15	0.10	0.15	0.15	0.10
Phytase	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CP %	16.81	15.81	13.80	15.26	14.13	12.49	14.53	13.75	12.35

a. For diet #1, 44% soybean meal is used. 48% SBM is used for #8 and #9.

4c) More Accurate P Requirement

Phase	NRC		Universities		Industry	
Corn[a]	78.35	81.10	78.15	80.60	77.75	80.50
SBM	17.85	15.60	17.85	15.60	17.85	15.60
Di-cal	2.35	1.82	2.56	2.31	2.9	2.47
Limestone	0.80	0.80	0.80	0.80	0.80	0.80
TMS	0.35	0.35	0.35	0.35	0.35	0.35
Vit Mix	.015	.015	.015	.015	.015	.015
Lysine	.015	.015	.015	.015	.015	.015
Phytase	0.00	0.00	0.00	0.00	0.00	0.00
CP %	0.50	0.40	0.54	0.49	0.60	0.52

a. Only Dical and Corn % are adjusted to meet the requirements.

Table V: ARC elasticity of nutrient excretion with respective to (w.r.t.) profit

Nutrient excretion strategies	Phase Feeding		Over-formulation		Meeting standards	
	1 phase to 2 phase	2 phase to 3 phase	high CP to med CP	med CP to low CP	by industry to by univ	by univ to by NRC
ARC Elasticity of nutrient excretion w.r.t. profit	4.7080	-0.7255	-1.0183	-0.5809	-2.1768	-2.4109

Footnote

1. Ford introduces 4 icon-based software programs for system dynamics: STELLA, Dynamo, Vensim, Powersim. Vensim stands out for its capability of handling stochastic variables, which gives an unsurpassed edge in sensitivity analysis. Spreadsheet programs (e.g. Excel by Microsoft) also can be used to model system dynamics but they require more effort and experience.

2. With load size of 170 pigs per truck (shipment size) and 4 shipments (1 truck, 2 trucks, 2 trucks, and 1 truck for each shipment) from a barn, it is assumed that 1020 pigs are placed for a batch.

3. Due to the development of objective measures of carcass leanness using new technology such as optimal probe and ultrasound scanners, carcass merit pricing systems for pork are becoming more common [6, 2].

4. In other studies, the pricing matrices are assumed to be smooth, continuous, and symmetric functions to avoid complication in analyses. However, the actual pricing matrix is usually a non-symmetric step function.

5. The weight partition can be translated into duration of feeding (because weight is a function of time) in a dynamic setting. Thus, in the actual analysis, days on each diet are the control variables. They are: 23 days on diet 1; 38 days on diet 2; 37 days on diet 3 for pigs shipped in the first the batch; 42 days on diet 3 for pigs shipped in the second batch; 50 days on diet 3 for pigs shipped in the third batch; and 53 days on diet 3 for the fourth batch of pigs shipped.

6. The reported average nutrient content (%) of corn and soybean meal in NRC [26] and UIUC CES [9] are different (CP in UIUC CES are higher). NRC [26] estimates of CP are used in the model. Thus, the estimated CP used by the model is lower than the CP estimated by UIUC CES [9] even though UIUC CES recommended diet formulations are used in the model. For P content in feedstuffs, the availability of P in feed is considered. Thus, if there is 0.28% P in corn, the actual available P in corn is 14% of 0.28% (0.28*0.14). Similarly, the available P in soybean meal is assumed to be 0.65*0.31. Therefore, P estimated by the model is lower than the P reported in diets by UIUC CES [9], even though the same diet formulations are used.

REFERENCES

Abdalla, C. and Y. Mo. 1999. Analysis of Swine Industry Expansion in the US: The Effect of Environmental Regulation. Conference on Consolidation in the Meat Sector. Regional Research Committee NE-165. Washington D.C.

Boland, M. A., E. P. Berg, J. T. Akridge, and J. C. Forrest. 1995. The Impact of operator error using optical probes to estimate pork carcass values. *Rev. Agri. Econ.* 17:193-204.

Boland, M. A., K. A. Foster, and P. V. Preckel. 1999. Nutrition and the Economics of Swine Management. *J. Agri. Appl. Econ.* 31:83-96.

Boland, M. A., P. V. Preckel. and K. A. Foster. 1998. Economics Analysis of Phosphorous-Reducing Technologies in Pork Production. *J. Agri. Res. Econ.* 23:468-482.

Boland, M. A., P. V. Preckel, and A.P. Schinckel. 1993. Optimal Hog Slaughter Weights Under Alternative Pricing Systems. *J. Agri. Appl. Econ.* 25:148-163.

Brorsen, B. W., J. T. Akridge, M. A. Boland, S. Mauney, and J. C. Forrest. 1998. Performance of Alternative Component Pricing Systems for Pork, *J. Agri. Appl. Econ.* 30:313-324.

Chauvel, J. and R. Ganier. 1999. Effect de l'alimentation multiphase sur la croissance et les rejets azotes du porc charcutier. *J. Rec. Porc.* France 28:249.

Chavas, J., J. Kliebenstein, and T. D. Crenshaw. 1985. Modeling Dynamic Agricultural Production Response: The Case of Swine Production, *Am. J. Agri. Econ.* 67:636-646.

Cooperative Extension Service. 2001. Pork Industry Handbook. *Swine Diets*. University of Illinois, Urbana-Champaign

Cromwell, G. L. 1989. An evaluation of the requirements and biological availability of calcium and phosphorous for swine. I*n* "Feed Phosphates in Monogastic Nutrition," Texas Gulf Nutrition Symposium. Raleigh, NC.

Cromwell, G. L. 1994. Feeding strategies urged as techniques to decrease pollution form hog manure, Feedstuffs, July 25, 1994.

Featherston, J. W. and J. D. Atwood. 1999. The Role of Economics in Producers' Waste Management Decision, *in* "Implementing animal waste management policy- federal, state, and Private Sector Perspectives," Organized Symposium held in conjunction with the 1999 American Agricultural Economics Association Meeting, Nashville, TN.

Flemming, R. A., B. A. Babcock, and E. Wang. 1998. Resource or Waste? The Economics of Swine Manure Storage and Management, Working paper, Center for Agri. and Rural Dev., Iowa State Univ. 97-WP 178.

Ford, A. 1999. *Modeling the Environment*, Island Press Washington D.C.

Hannon, B. and M. Ruth. 1997. *Modeling Dynamic Biological Systems,* Springer- Verlag New York.

Henry, Y. and J. Y. Dourmad. 1993. Feeding strategies for minimizing nitrogen outputs in pigs, *in* "Nitrogen flow in pig production and environmental consequences." Proc. First Int. Symp. Nitrogen flow in Pig Production and Environmental Consequences, EAAP Publication No. 69. P 137.

Hurt, C. 1994. Industrialization in the Pork Industry, CHOICES, 4th quarter, pp. 9-13.

Innes, R. 2000. The Economics of Livestock Waste and Its Regulation, *Am. J. Agri. Econ.* 82:97-117.

Kerr, B. J. and R. A. Easter. 1995. Effect of feeding reduced protein, amino acid supplemented diets on nitrogen and energy balance in grower pigs, *J. Anim. Sci.* 73:3000.

Kornegay, E. T. and A. F. Harper. 1997. Environmental Nutrition: Nutrient Management Strategies to Reduce Nutrient Excretion of Swine, *The Prof. Anim. Scientist* 13:99-11.

Lawrence, J. D. 1996. Factors that influence prices producers receive for hogs: statistical analysis of kill sheet and survey data. Staff paper, Dept of Econ., Iowa State Univ. No. 279.

Lawrence, J., G. Grimes, and M. Hayenga. 1998. Production and Marketing Characteristics of U.S. Pork Producers, 1997-1998, Staff paper, Dept. Econ., Iowa State Univ. No. 311.

Miller, G. Y, Y. Song, and P.B. Bahnson. 2000. An Economic Model for Estimating Batch Finishing System Profitability with an Application to Preventing Porcine Respiratory Disease Complex, Submitted to Swine Health and Production.

NRC. 1987. Predicting Feed Intake of Food-Producing Animals. National Academy Press, Washington D.C.

NRC. 1988. Nutrient requirement of swine, 9th rev. ed. National Academy Press, Washington, D.C.

NRC. 1998. Nutrient requirements of swine. 10th rev. ed. National Academy Press, Washington, D.C.

Parks, J. R. 1982. A Theory of Feeding and Growth of Animals, Springer-Verlag, New York.

Rhodes, J. 1995. The Industrialization of Hog Production, *Rev. Agri. Econ.* 17:107-118.

Roka, F. M. and D. L. Hoag. 1996. Manure Value and Liveweight Swine Decision. *J. Agri. Appl. Econ.* 28:193-202.

Ruth, M. and B. Hannon. 1997. Modeling Dynamic Economic Systems. Springer- Verlag New York.

Van der Honing, Y., A. W. Jongbloed and N. P. Lenis. 1993. Nutrition management to reduce environmental pollution by pigs, VII World Conf. On Anim. Prod., Edmonton, Alberta, Canada.

APPENDIX

List of Abbreviation for the Appendix

ADG : Average Daily Gain

AE : Antibiotic Effect

BE : Breed Effect

BW : Body weight

CV : Coefficient of Variation

D : Digestibility

DE : Digestible Energy

DER : Daily Energy Requirement

DF : Daily Feed required

DFI : Daily Feed Intake

DNF : Daily Nutrient excreted as Feces

DNR : Daily Nutrient Retained

DNU : Daily Nutrient excreted as Urine

EAT : Effective Ambient Temperature

ELC : Energy Level Coefficient

ET : Environmental Temperature

IR : Ingredient Ratio

K : Potassium

M : Meal effect on DFI

ME : Metabolizable Energy

N : Nitrogen

NRC : National Research Council

P : Phosphorous

PDE : Pen Density Effect

PR : Price

R : Retainability

SBM : Soybean Meal

SE : Sex Effect

TC : Total Cost

TER : Total Energy Requirement

TFI : Total Feed Intake

TR : Total Revenue

TWT : Total Weight

Growth Model

Our growth model is based on NRC's pig growth model [15]. To fit the ADG suggested by NRC [16], the following ADG equation is used.

$$ADG^{w/o} = \frac{dBW^{w/o}}{dt} = 463.321 + 11.643 \cdot BW - 0.0635 \cdot BW^2$$

where $ADG^{w/o}$ is ADG without Feed Type Effect and $BW^{w/o}$ is Body Weight without Feed Type Effect. DE^{feed} is defined from diet formulation assuming

DE in feed for corn = (1550 Kcal/lb)/0.96 and

DE in feed for SBM = (1535 Kcal/lb)/0.96.

Also assuming

Metabolizable Energy (*ME*) = *DE**0.96

[15] and 1 lb corn holds 1550 Kcal of energy and 1 lb of SBM holds 1535 Kcal of energy [3]. Also lb is converted into gram.

Thus, *DE* from daily feed intake is

$$DE^{feed} = DFI \cdot (IR^{corn} \cdot 1550/0.96 + IR^{SBM} \cdot 1535/0.96)$$

where *DFI* is Daily Feed Intake (lb) and IR^j is Ingredient Ratio of ingredient j.

Feed Type Effect on ADG: Average daily gain industry standard difference is 7 %. Thus, if feed type is meal,

$$\frac{dBW}{dt} = ADG = ADG^{w/o}$$

If feed type is pellet,

$$\frac{dBW}{dt} = ADG = ADG^{w/o} \cdot 1.07$$

Daily Energy Requirement

Daily Energy Requirement is defined as follows

$$\frac{dTER}{dt} = DER = (DE^{req} \cdot BE + ELC) \cdot ET$$

where DE^{req} is Digestible Energy required, *BE* is Breed Effect Coefficient, *ELC* is Energy Level Coefficient, and *ET* is Environment Temperature Coefficient.

DE^{req} with SE (Sex Effect) is defined as in ARC [1]

$$DE^{req} = 1123 \cdot BW^{0.51} \cdot SE$$

where Mahan and Gerber [10] claim pig needs DE of 9107 Kcal/day, the barrow needs + 5.7%, and the gilt uses - 5.7 % per day, the boar has the greatest demand per day. Thus,

If sex is barrow then *SE* = 1+ 0.057
If sex is gilt then *SE* = 1 -0.057
If it is neither barrow or gilt (boar, for example), *SE* = (1+0.070)

BE is defined as

if Breed is Duroc, *BE* = 1+3.8/100
if Breed is Hampshire, *BE* = 1
if Breed is Yorkshire, *BE* = 1+1.8/100
if Breed is Poland China, *BE* = 1+1.8/100
if Breed is Spotted Poland China, *BE* = 1+1.7/100
if Breed is Landrace, *BE* = 1+(-3.3)/100
if Breed is Crossbred, *BE* = 1+5.6/100

Reference for these equations are : Bereskin et al.[2] for Duroc, Johnson[6] for Hampshire and Crossbred, McPhee[12] for Yorkshire and Landrace, and Quijandria [17] for Poland China and Spotted Poland China.

ELC is defined as follows. Leibbrant et al.[9] and McConnel et al. [11] claims DE intake increases as energy density increases. Thus,

If 5kg < *BW* < 30kg and $DE^{feed} < 3300$, then $ELC = (3300 - DE^{feed}) * (-1388)/1000$
If 5kg < *BW* < 30kg and $3300 \leq DE^{feed} < 3600$, then $ELC = 0$
If 5kg < *BW* < 30kg and $3600 \leq DE^{feed}$, then $ELC = ((DE^{feed} - 3600) * 138/1000)$
If 30kg ≤ *BW* and $DE^{feed} < 3300$, then $ELC = (3300 - DE^{feed}) * (-2773/1000)$
If 30kg ≤ *BW* but $DE^{feed} \geq 3300$, then $ELC = 0$.

Verstegen et al.[19]: Environmental temperature affects optimum feed intake. *ET* is defined as

ET = 1 + ((Pig's Optimum Environmental Temperature - (Ambient Temp + Air Speed Coefficient + Floor Effect))*0.0165)

where Heitman et al. [5] : Body weight affects the optimum temperature.

Pig's Optimum Environmental Temperature = 26 - 0.0614**BW*.

and Mount [14] : Air movement decreases EAT when increasing the rate of convective and evaporative heat loss.

if Air Speed in Building (m/sec) < 0.2 then 0
if 0.2 < Air_Speed_in_Building < 0.5 then -4
if 0.5 < Air_Speed_in_Building < 1.5 then -7
if 1.5 < Air Speed in Building then –10

Mount [14] : Floor type changes effective ambient temperature. That is,

for straw bedding Floor Effect = 4,
for concrete slats Floor Effect = - 5,
for wet surfaces Floor Effect = -5 to -10.

Daily Feed Intake is defined as follows.

$$DFI = \frac{dTFI}{dt} = DFI^{req} \cdot PDE \cdot (1 + AE) \cdot (1 + M)$$

where

$$DF^{req} = DE^{req} / DE^{feed}$$

Pen Density Effect : Kornegay and Notter [8] unit of density = m2/pig

If Pen Density <1.06,
PDE = (77.25 + 42.93 * Pen Density - 20.25 * Pen Density * Pen Density)/100

If 1 ≤ Pen Density, $PDE = 1$

Antibiotic Effect : Hays [4]: Pigs fed antibiotics consumed 8 % more than control pigs fed diets without antibiotics in starter phase, 6 % more in grower phase, and 2% more in finishing phase.

if BW < 20: with Antibiotics, $AE = 0.08$. without Antibiotics, AE = 0
if 20 ≤ BW <50: with Antibiotics, $AE = 0.06$, without Antibiotics, AE = 0
if 50 ≤ BW : with Antibiotics, $AE = 0.02$, without Antibiotics, AE = 0

M, Meal Effect on DFI : Van Choubroek et al. [18] concluded that pellet reduced feed intake by 3.1 %. If feed type is pellet, $M = -0.031$. If feed type is meal, $M = 0$.

Nutrient Excretion Model

Assuming digestibilities and retainabilities [7] for different nutrients and different pigs, we can construct a linear nutrient excretion function as defined as follows.

Daily Nutrient Excretion as Feces = Daily Intake (kg)*[Ingredient Ratio_Corn*Nutrient Ratio_Corn*(1 – Digestibility of Nutrient) + … + Ingredient Ratio_Lysine*Nutrient Ratio_Lysine*(1 – Digestibility of Nutrient)]

Daily Nutrient Excretion as Urine = Daily Intake (kg)* [Ingredient Ratio_Corn*Nutrient Ratio_Corn* Digestibility of Nutrient*(1 – Retainability of Nutrient) + … + Ingredient Ratio_Lysine*Nutrient Ratio_Lysine* Digestibility of Nutrient*(1 – Retainability of Nutrient)]

Daily Nutrient Retained = Daily Intake of Pig (kg)* [Ingredient Ratio_Corn (%)*Nutrient Ratio_Corn (%)* Digestibility of Nutrient*Retainability of Nutrient + … + Ingredient Ratio_Lysine (%)*Nutrient Ratio_Lysine (%)* Digestibility of Nutrient*Retainability of Nutrient]

Formally,

$DNF_i^m = DF_m \cdot \sum IR_m^j \cdot NR_i^j \cdot (1 - D_m^i)$ = Daily Nutrient i excreted as feces from m

$DNU_i^m = DF_m \cdot \sum IR_m^j \cdot NR_i^j \cdot D_m^i \cdot (1 - R_m^i)$ = Daily Nutrient i excreted as urine from m

$DNR_i^m = DF_m \cdot \sum IR_m^j \cdot NR_i^j \cdot D_m^i \cdot R_m^i$ = Daily Nutrient i retained from m

where

D_m^i = Digestibility of i for m

R_m^i = Retainability of i for m
IR_m^j = Ratio of Ingredient j for m
NR_i^j = Ratio of Nutirent i in j
DF_m = Daily Feed Intake of m

i = N, P, K
j = ingredient; corn, SBM, Dical PO4, Limestone, Trace Min Salt, Vit Mix, Lysine
m = classification of pig; gestating sow, lactating sow, … , 140 lb to market

The diet formulation component from this excretion model feeds back to the nutrition model to provide the Digestible Energy. The amount of Daily Feed Intake feeds back from the nutrition model to this excretion model to affect the amount of nutrient excreted. The live body weight estimated from the nutrition model is used to estimate the revenue and amount of feed consumed is used to estimate the feed cost, which is dominant in cost of swine production in the following economic component of the model.

Economic Component

Integration of Pricing Matrix

It is assumed that the coefficient of variation (CV) is constant in time, t. That is,

$$CV = \frac{\sigma(t)}{\mu(t)}$$

where, μ, average weight and standard deviation, σ, are functions of time.
Thus, σ changes as μ changes, assuming CV is constant over time.

To estimate the proportion of weight generated for each weight ranges, i, we use the normal probability density function

$$\int_{X'_{\min}}^{X'_{\max}} \frac{1}{\sigma\sqrt{2\pi}} e^{-(y-\mu)^2/2\sigma^2} dy$$

where $X'_{\min}$ is the minimum of the range and $X'_{\max}$ is the maximum of the range. However, a closed-form expression for the integral does not exist [13]. Thus, an approximated table for normal curve area is used. However, the table provides approximation for only right half of normal curve.

To include another half, the following procedure is integrated. That is, to calculate any area between any two values, define z value for the minimum value as follows

$$z^{i}_{\min}(t) = \frac{|X^{i}_{\min}(t) - \mu(t)|}{\sigma(t)}$$

The z table is integrated into the model. Then,

If $X^{i}_{\min} - \mu \geq 0$,

$$\int_{X^{i}_{\min}}^{\infty} \frac{1}{\sigma\sqrt{2\pi}} e^{-(y-\mu)^2/2\sigma^2} dy = 0.5 - \int_{0}^{X^{i}_{\min}} \frac{1}{\sigma\sqrt{2\pi}} e^{-(y-\mu)^2/2\sigma^2} dy .$$

Otherwise,

$$\int_{X^{i}_{\min}}^{\infty} \frac{1}{\sigma\sqrt{2\pi}} e^{-(y-\mu)^2/2\sigma^2} dy = 0.5 + \int_{0}^{X^{i}_{\min}} \frac{1}{\sigma\sqrt{2\pi}} e^{-(y-\mu)^2/2\sigma^2} dy .$$

Likewise,

$$z^{i}_{\max}(t) = \frac{|X_{\max}(t) - \mu(t)|}{\sigma(t)}$$

If $X^{i}_{\max} - \mu \geq 0$,

$$\int_{X^{i}_{\max}}^{\infty} \frac{1}{\sigma\sqrt{2\pi}} e^{-(y-\mu)^2/2\sigma^2} dy = 0.5 - \int_{0}^{X^{i}_{\max}} \frac{1}{\sigma\sqrt{2\pi}} e^{-(y-\mu)^2/2\sigma^2} dy .$$

Otherwise,

$$\int_{X^{i}_{\max}}^{\infty} \frac{1}{\sigma\sqrt{2\pi}} e^{-(y-\mu)^2/2\sigma^2} dy = 0.5 + \int_{0}^{X^{i}_{\max}} \frac{1}{\sigma\sqrt{2\pi}} e^{-(y-\mu)^2/2\sigma^2} dy .$$

Then the area between $X^{i}_{\min}$ and $X^{i}_{\max}$ can presented as

$$\int_{X^{i}_{\min}}^{\infty} \frac{1}{\sigma\sqrt{2\pi}} e^{-(y-\mu)^2/2\sigma^2} dy - \int_{X_{\max}}^{\infty} \frac{1}{\sigma\sqrt{2\pi}} e^{-(y-\mu)^2/2\sigma^2} dy .$$

A revenue from pigs with weights between $X^{i}_{\min}$ and $X^{i}_{\max}$ is then

$$TR^i(t) = TWT(t) \cdot \int_{X^i_{min}}^{X^i_{max}} \frac{1}{\sigma\sqrt{2\pi}} e^{-(y-\mu)^2/2\sigma^2} dy \cdot (PR_{hog} - PR^i_{penalty})$$

where $TWT(t)$ is total weight at t, PR_{hog} is price of hog (\$/cwt), and $PR'_{penalty}$ is penalty for weight range i. Summation of these revenues, i, gives Total Revenue,

$$TR(t) = \sum TR'(t).$$

Integration of Cost Function

A simple linear cost function is used. That is,

Total Cost; TC (t) = feed cost (per lb of weighted average for corn, SBM, mix and mixing) + other costs (per head other cost * number of pigs) + feeder pig cost (per head feeder pig cost * number of pigs)

TR(t) and TC(t) are calculated to provide the profit daily.

Profit function

Profit, or revenue over cost, is define as

$$\pi(t) = TR(t) - TC(t).$$

REFERENCES FOR APPENDIX

Agricultural Research Council. 1981. The Nutrient Requirements of Pigs. Slough, England: Commonwealth Agricultural Bureaux.

Bereskin, B, R. J. Davey, W. H. Peters, and H.O. Hetzer. 1975. Genetic and environmental effects and interactions in swine growth and feed utilization, J. Anim. Sci. 40:53.

Cooperative Extension Service. 2001. Swine Diets. Pork Industry Handbook, University of Illinois, Urbana-Champaign.

Hays, V. W. 1979. Effectiveness of feed additives usage of antibacterial agents in swine and poultry production, in "Drugs in Livestock Feed," Vol 1 Washington, D.C., United States Congress, Office of Technology Assessment.

Heitman Jr., H., C. F. Kelly, and T.E. Bond. 1958. Ambient air temperature and weight gain in swine, J. Anim. Sci. 17:62.

Johnson, R. K., I.T. Omtvedt, and L.E. 1973. Walters, Evaluation of purebreds and two-breed crosses in swine: Feedlot performance and carcass merit, J. Anim. Sci. 38:18.

Kornegay, E. T. and A. F. Harper. 1997. "Environmental Nutrition: Nutrient Management Strategies to Reduce Nutrient Excretion of Swine." The Prof. Anim. Scientist 13:99-11.

Kornegay, E. T. and D.R. Notter. 1984. Effects of floor space and number of pigs per pen on performance. Pig News and Information 5:23.

Leibbrant, V. D., R.C. Ewan, V.C. Speer, and D.R. Zimmerman. 1975. Effect of age and calorie: protein ratio on performance and body composition of baby pigs, J. Anim. Sci 40:1070.

Mahan, D.C. and D. B. Gerber. 1984. Gilt and barrow performance responses from 130 to 300 pounds body weight. P. 1 in Ohio Swine Research and Industry Report, State University Animal Science Series Publication No. 84. Columbus, Ohio.

McConnel, J. G., M. W. Stuck, R. C. Waldorf, W.P. Bryd, and L. W. Grimes. 1982 Calorie requirements of early weaned pigs fed corn-soybean meal-based diets. J. Anim. Sci. 55:841.

McPhee, C. P., P.J. Brennan, and F. Duncalfe. 1979. Genetic and phenotype parameters of Australian Large White and Landrace boars performance-tested when offered food ad libitum, Anim. Prod. 28:79.

Mendenhall, W., D.D. Wackerly, and R.L. Scheaffer. 1990. Mathematical Statistics with Applications, 4th ed. Belmont, CA. Duxbury Press.

Mount, L. E. 1975. The assessment of thermal environment in relation to pig production. Live. Prod. Sci 2:381.

NRC. 1987. Predicting Feed Intake of Food-Producing Animals, National Academy Press, Washington, D.C.

NRC. 1998. Nutrient Requirement of Swine, 10th rev. ed. National Academy Press, Washington, D.C.

Quijandria Jr., B., J.R. Woodard, and O. W. Robinson. 1970. Genetic and Environmental effects on live and carcass traits at the North Carolina Swine Evaluation Station, J. Anim. Sci. 31:652.

F. VanChoubroek, L. Coucke, and R. VanSpaendonk. 1971. The quantitative effect of pelleting feed on the performance of piglets and fattening pigs, Nutr. Abstr. Rev. 41:1.

Verstegen, M. W. A., E.W. Brascamp, and W. Van Der Hel. 1978. Growing and fattening of pigs relation to temperature of housing and feeding level, Can J. Anim. Sci 58:1.

Management and other Factors that Influence Air Quality and Odor

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Swine odor and manure management are important for the long term vitality of the swine industry in Illinois. Odor complaints for existing facilities can be quite difficult for a producer to know what to do in attempting to decrease odor emitted from the farm. Odor is related to many different factors, some of which can be controlled by producers and some which cannot be controlled by producers. This project investigated the controllable and uncontrollable factors that were related to the amount of odor emitted from swine finishing buildings.

We monitored 26 buildings on 10 different farms, with buildings from a farm monitored on four different days over the course of a 15 month period. Each farm visit was separated by 3-4 months. During our farm visits, we collected data and samples for measuring air quality and odor. Barn inspections were conducted to determine barn cleanliness, surface dustiness, air cleanliness, type of feed (pelleted or ground), problems with dunging, depth of manure in the pit, and type of pit (either shallow (<4 f; manure stored < 2 wks) or deep (>4 f; manure stored >6 mo)). Other data recorded and observations made were inventory of pigs in the barn, barn dimensions and layout in order to estimate floor space/pig, pig size, and a general impression of pig health. Several measures relating to air quality and air characteristics were recorded. We measured air temperature, relative humidity, carbon dioxide, ammonia, and hydrogen sulfide concentrations. We collected bagged air samples from barn inlets and exhausts, and recorded information on the number and size of fans that were running at the time of sample collection, and from which of the fans samples were collected.

The bagged air samples were analyzed for odor by an eight-person odor sensory panel. Each person was presented an air sample from the farm which had been diluted by a controlled amount. Each person is simultaneously presented with room air samples. The dilutions are changed after each round of sniffing three samples (two with only room air and one diluted with the farm air), so that the sample becomes less dilute (has more air from the farm in the air that is sniffed). Each person is then asked when they believe that they can just distinguish the room air samples from those samples that are mixed with air from the farm. The machine used for this process is called a dynamic olfactometer, and has become a standard method for evaluation of odor detection. Recordings of the

amount of sample when accurate detection occurs are an indication of the "amount" of odorous compounds in the sample.

One goal of our overall project was to be able to look at correlations and statistical relationships to see what we could learn about the factors on the farm that are most closely linked to odor emission rates from these 26 mechanically ventilated swine buildings. What we learned was interesting. Of the variables studied, there are some which are outside of the control of the producer that are statistically associated with odor. These factors included season, ambient temperature, and relative humidity. Thus, it is clear that producers have times when odor is more likely to be higher because of these uncontrollable factors. The spring season had the lowest odor emission rates of any season. As temperature and relative humidity increased, odor emissions decreased. We are uncertain as to why this occurred but believe it may be because of the complex relationships between humidity and dustiness, the water carrying capacity of air as temperature increases, and the affinity of water molecules to odorous compounds. There are other factors which are at least somewhat controlled or completely controllable by the producer that influence odor. These factors included manure depth, floor-space per pig, barn cleanliness, air cleanliness, pit type (deep or shallow), and pig health. As manure depth increased, so did odor emissions. While building type cannot be changed in the short run, the choice of pit depth is within the control of the producer at the time of construction. Barns with deep pits were found to emit less odor than a comparable building with a shallow pit. This relationship held as long as the manure depth in the deep pit was less than approximately 3 feet. Other management variables studied had predictable associations with odor emissions. For example, barns with more space per pig emitted less odor. Barns with cleaner air emitted less odor. However, some of the barn management observations were not related to odor in the way we would have anticipated. For barn cleanliness, and pig health, these factors had opposite effects than we predicted. As barn cleanliness improved, odor emitted increased. Also when pig health was good, odor emitted increased. Panelist was also an important variable in explaining ability to detect odor in air samples. The statistics associated with known factors (those mentioned above) could explain only about half of what causes barn-to-barn variability in odor emissions. The other half of the variability in odor emissions is occurring for reasons that we could not explain based on our observational study. Thus, not only are there uncontrollable factors that influence odor emissions, there are a lot of other unobserved (at least in this study) factors which influence odor. The variables from our study which did not appear to be associated with odor emissions included feed type (pelleted or ground), surface dustiness, and dunging.

The full report of this study is currently under consideration for publication in a refereed journal. A copy of our preprint manuscript is available upon request.

Another goal of this project was to use the results from this study where we were able to find relationships between management factors and odor emissions in combination with costs to be able to estimate the cost-effectiveness of different control strategies a producer might use when attempting to decrease odor emissions. This cost-effectiveness analysis is reported on separately (summary of this study is included in this Proceedings).

Cost-effective Catalytic Methods to Reduce Gaseous Emissions from Swine Facilities

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It has been estimated that about half of the odorous emissions from swine facilities originate in the buildings themselves. Other work in the Illinois C-FAR Swine Odor and Waste Management Strategic Research Initiative has addressed gaseous emissions from manure pits and lagoons as well as dust emissions. But emissions of gaseous components from the houses *per se* has not been addressed in the SRI.

Objective and Approach

The objective of our project in this Initiative was to develop cost-effective catalytic converters for retrofitting swine-house ventilation outlets so as to reduce odor emissions. As described and discussed later in this paper, we have gone a long way toward realizing that goal.

Our approach has been to use a catalyst to convert the odorous molecules into something benign. We have concentrated on catalytic systems because, in other industries, they have proven to be very cost effective. The catalysis process generates heat and removes toxic and irritating compounds, thereby reducing the need for ventilation. In other industries, the savings from reduced ventilation and heating costs have paid for the catalytic treatment system.

Advantages of the Catalytic Approach

We have surveyed available technologies and believe that catalytic systems hold the most promise. In our opinion there are valid reasons the catalytic approach to be advantageous relative to either ozonation or biofiltration.

Ozonation reacts odorous molecules with ozone. This is useful for treating odors in liquids, but it is not commonly used to treat gaseous emissions. The difficulty is that ozone is irritating and toxic. The threshold limit value is 100 parts per billion (ppb). Toxic effects have been reported at 60 ppb. If ozone were released into the air in a swine house, it would diffuse throughout the building and predictably would adversely affect the health of pigs and people alike.

Biofiltration is another potential technology. Biofilters work similarly to catalyic methods, and can be used to clean the air in swine houses. But, although biofilters have been studied for 20 years, they remain extremely expensive to operate.

Catalytic converters are a third alternative. At present, to our knowledge, no one else has explored the possible use of catalytic converters for odor reduction in swine-house air. Yet they are the standard technology for destruction of odorous molecules in automotive exhaust, power plants, wood stoves, and chemical plants. In Japan, catalytic converters also are used to reduce odors in toilets. They usually are very cost-effective systems with modest installation cost and low maintenance cost. We have done preliminary economic analysis which projects a cost of $0.23 per 100 lb of liveweight produced. Although these initial projections may ultimately prove to be low, they are quite attractive when contrasted with the $4 to$16 per100 lb of liveweight produced for biofilters.

So at the outset catalytic converters deserved attention in this critical issue area because they should be much less expensive than biofilters, and have none of the irritant and toxic side-effects of ozonation.

RESULTS

Early laboratory studies demonstrated that a key component in swine odor -- acetic acid – can be removed from an air stream by a copper catalyst. Conversion of acetic acid was easier and more complete than had been expected, and the catalyst was inexpensive. Catalytic methods are feasible for reduction of odor in exhaust air.

Subsequent laboratory studies demonstrated for the first time that odorous molecules in a simulated swine-odor mixture were rapidly adsorbed on a copper/magnesia catalyst and then easily converted to carbon dioxide and water upon heating the catalyst. Moreover, although most odor-cleanup systems produce waste products containing odorous molecules, with catalytic approaches odorous molecules are incinerated and *no new toxic or odorous molecules are generated.*

Initial field studies at the UIUC swine farms using a very inexpensive catalyst demonstrated that odors were indeed removed from barn-exhaust air. Early designs did have too much flow restriction (generating back pressure) to be practically useful, but there are standard approaches to overcoming these difficulties, and these should be addressed in the near future (see below). These results showed that catalytic methods also hold promise of being *cost-effective ways to treat exhaust gases from swine facilities.*

Alas, lightoff temperature (*i. e.*, the temperature required to burn off the adsorbed odorous compounds) was higher than anticipated and flow restrictions were much higher than desired. Again, with doable development, these issues can and should be addressed in the near future (see below), and *catalytic odor-control methods in swine facilities should then be effective, feasible, and cost-effective.*

Cost-effectiveness

The catalyst is inexpensive. Around $0.50 worth of catalyst will effectively treat the acid emissions from one sow. We had only about 10 grams of catalyst in this experimental system (catalyst costs only around $20 per lb), yet with this amount destroyed about 0.2

gm of acetic acid per hour. According to North Carolina State University reports, one sow produces about 0.1 gram of volatile acids per hour. The implication here is that about $0.50 worth of catalyst suffices to destroy the acids produced by about two sows. Of course, there will be system costs in addition to the cost of the catalyst, but clearly this approach seems to be very cost-effective.

Remaining Challenges

Remaining challenges should be addressed by (1) trying some standard tricks (*e. g.*, V-bed designs) to reduce the pressure drop, and (2) generating the engineering data and on-farm trial-and-error testing needed to translate these results into practical on-farm solutions to the problem of swine odor.

A rational general plan would be to start with a commercial regenerable tray adsorber, and to replace its standard adsorbent with the catalyst mixtures developed in the first three years of this project. These devices should be tested first in the laboratory. Then the development process should be moved to on-farm proving centers for detailed tests of their effectiveness in odor reduction under realistic conditions. Sampling of inlet and outlet air streams should be done as a function of exhaust flow rate so catalyst effectiveness and how that effectiveness changes over time can be evaluated. Samples of catalysts that have been used in those tests should be analyzed to learn what is accumulating on the catalyst surfaces in developing effective regeneration procedures. The catalyst mixture should be modified as indicated to ensure effective odor removal, low cost, and long life.

Coda

Our laboratory has significant funding from several nonagricultural sources to continue development of catalytic methods of odor reduction. Spin-off from this continuing research will be further development of this approach for application to odor reduction at swine facilities.

REFERENCES

Ali, Nasir, Chang Lu, Richard Masel. Catalytic oxidation of odorous organic acids. *Catalysis Today* 62 ;347-353, 2000.

Mutlu, A., Y. Zhang, R. Masel, G. L. Riskowski, M. Ellis. Reduce odor emission from swine buildings using a catalytic converter filter. *Proceedings* Third International Conference on Air Pollution from Agricultural Operations. North Carolina State University, Raleigh. October 12-15, 2003.

OVERVIEW OF INNOVATION IN MANURE PROCESSING TECHNOLOGIES – Efforts at North Carolina State University funded by the Attorney General Agreements with Smithfield Foods, Premium Standard Farms and Frontline Farmers

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INTRODUCTION

The impact of animal agriculture on the environment attributed to the production of meat, eggs and milk are significant issues facing the livestock industry, intensive swine production in particular. In the United States and elsewhere, researchers are expending considerable resources efforts to develop innovative manure treatment technologies to address these issues. The attention that is directed to the development of new animal waste treatment technology involves academic institutions, government, and the private sector, including the animal production industry. Prior to this decade, research has arguably been more intensive in Western Europe because of limited land area resulting in more urban pressure on animal agriculture. In 1997, fifteen experienced researchers from eleven countries, mostly in Western Europe, published a book entitled MANURE MANAGEMENT, TREATMENT STRATEGIES FOR SUSTAINABLE AGRICULTURE (BURTON, 1997). These researchers basically defined the "state of the art" of animal manure management and concluded that a range of treatments are available that can address many of the identified environmental issues. Available treatments included aeration, anaerobic digestion including lagoons, solids separation, and composting. New processes that were identified as potentially effective included thermal treatments, purification by soil, use of chemical additives, and membrane processes. However, it was noted that if the use of manure is to be other than direct land application as a source of plant nutrients, there are economic challenges to developing commercially competitive organo-fertilizers or other alternative co-products.

Many stakeholders involved in animal waste treatment issues assume that there are readily available alternative management technologies that have been adequately developed and verified to the point that they can replace existing systems. However, while there are a number of different technologies and management systems available, the practicality of applying many of these alternative technologies is largely unproven at the present time. For example, many

promising alternative technologies generate solids but only limited viable markets have been identified or established for the end products; this limitation significantly impacts the economic feasibility of the technology. In addition, some candidate replacement systems have not performed well under performance verification testing or are cost-prohibitive. Other potential replacement technologies are still in field trials and need further evaluation before any definitive conclusions can be reached. The present level of research, development, and demonstration efforts, however, provides optimism that innovative alternatives may be developed and proven practical in the future.

North Carolina State University Research – The Attorney General Agreements[1]

The Attorney General of North Carolina entered into Agreements in July and September 2000 with Smithfield Foods and Premium Standard Farms (PSF), respectively, to develop "Environmentally Superior Technologies" (EST) for implementation onto farms located in North Carolina that are owned by these companies. In March 2002, the Attorney General also entered into an Agreement with Frontline Farmers in which its membership agreed to work cooperatively with the Attorney General and North Carolina State University (NCSU) to develop and implement EST. The Smithfield Foods Agreement provides $15 million and, to date, the NC Attorney General has allocated $2.3 million from the PSF Agreement for a total of $17.3 million for the EST identification and development initiative.

The Agreements define EST as "any technology, or combination of technologies that (1) is permittable by the appropriate governmental authority; (2) is determined to be technically, operationally, and economically feasible for an identified category or categories of farms as described in the Agreements and (3) meets the following performance standards:

1. Eliminate the discharge of animal waste to surface waters and groundwater through direct discharge, seepage, or runoff,
2. Substantially eliminate atmospheric emissions of ammonia,
3. Substantially eliminate the emission of odor that is detectable beyond the boundaries of the parcel or tract of land on which the swine farm is located,
4. Substantially eliminate the release of disease-transmitting vectors and airborne pathogens, and
5. Substantially eliminate nutrient and heavy metal contamination of soil and groundwater."

Selection of EST candidates to undergo performance verification and economic analysis involved a request for proposals that was issued nationwide to research institutions and industry. Selections were based on terms and conditions of the Agreements and competitive review (outside *ad hoc* review) as well as review by an Advisory Panel appointed per the Agreements and comprised of individuals that represent government, environmental and community interests, the companies (Smithfield, PSF and Frontline Farmers) and individuals with expertise in animal

[1] Sections of the following text are published, in part, in *Proceedings North Carolina Animal Waste Management Workshop*. October 16-17, 2003, Research Triangle Part, NC. Edited by G.B. Havenstein, published by College of Agriculture and Life Sciences, NCSU. Pages 14-18 (2003).

waste management, environmental science and public health, economics and business management. Collectively, this process yielded the following EST candidates:

1. In-ground ambient temperature anaerobic digester / energy recovery / greenhouse vegetable production system,
2. High temperature thermophilic anaerobic digester (TAnD) energy recovery system,
3. Solids separation / constructed wetlands system,
4. Sequencing batch reactor (SBR) system,
5. Upflow biofiltration system,
6. Solids separation / nitrification-denitrification / soluble phosphorus removal /solids processing system,
7. Belt manure removal and gasification system to thermally convert dry manure to a combustible gas stream for liquid fuel recovery,
8. Ultrasonic plasma resonator system,
9. Manure solids conversion to insect biomass (black soldier fly larvae) for value-added processing into animal feed protein meal and oil system,
10. Solids separation / reciprocating water technology system,
11. Micro-turbine co-generation system for energy recovery,
12. Belt system for manure removal,
13. High-rate second generation totally enclosed Bion system for manure slurry treatment and biosolids recovery,
14. Combined in-ground ambient digester with permeable cover / aerobic blanket - BioKinetic aeration process for nitrification-denitrification / in-ground mesophilic anaerobic digester system (this project represents 3 farm sites),
15. Dewatering / drying / desalinization system,
16. Solids separation / gasification for energy and ash recovery centralized system (this project represents 3 farm sites),
17. High solids high temperature anaerobic digester system, and
18. Solids separation / mesophilic anaerobic digestion / membrane filtration – reverse osmosis system.

EST Process Analysis

Performance verification and economic feasibility analysis for candidate EST located on commercial farm sites involves a 15-step systematic process: 1) EST candidate selection through a request for proposals and competitive review process, 2) selection of appropriate commercial farm or university research site for the technology study, 3) execution of farm owner agreement, 4) execution of technology design agreement, 5) development of technology design documents, 6) submittal, review and approval of design documents by NC Department of Environment and Natural Resources (NCDENR) for permitting purposes, 7) execution of technology construction agreement, 8) on-site construction, 9) execution of agreements for technology operation and post-evaluation decommission (if necessary), 10) construction closure approval, 11) establishment of functional operation of technology (e.g. steady state waste treatment conditions), 12) procurement of environmental performance data and economic feasibility data by third party research teams, 13) analysis of data and results reporting to the Advisory Panel, Designee, and public, 14) input and review process by the advisory panels, and 15) EST

technology determinations per terms and conditions of Agreements. A progress report describing the detail of the activities related to each of these steps between the dates of July 25, 2000 and July 25, 2002 was previously published (Williams, 2002).

Current Construction, Operational and Performance Data Procurement Status

In addition to the progress made during the past year relative to constructing and bringing the technologies to operational conditions, environmental performance data procurement and economic assessment has occurred for the following technologies:

(Project 1) Ambient Digester / Greenhouse tomato production,
(Project 3) Constructed wetlands,
(Project 5) Upflow biofilter,
(Project 10) Reciprocating wetland,
(Project 6) Super Soil Systems,
(Project 7) Belt Manure / Gasification System (belt component only),
(Projects 9 & 12) Belt Manure System / Manure Conversion to Insect Biomass,
(Project 16) Solids Separation / Ash Recovery,
(Project 11) Microturbine Co-Generation, and
(Project 14) Mesophilic Digester / Permeable cover.

Full progress reports by project investigators for many of these projects have been published (Williams, 2003).

Status of Emission Analysis

Emissions of odor, pathogens and nitrogen were conducted for several project sites during this reporting period. Investigators for this component of the performance verification process, Project OPEN (Odor, Pathogens, and Emissions of Nitrogen) demonstrated the effectiveness of a new paradigm for policy-relevant environmental research. This new paradigm is based on a commitment to improve scientific understanding associated with all aspects of environmental issues (air, water, soil, odor and odorants, and disease-transmitting vector and airborne pathogens) and, as part of a comprehensive strategy, to facilitate in the development, testing and evaluation of potential Environmentally Superior Technologies for the management of swine waste. The OPEN team, comprised of scientists and engineers from three universities (North Carolina State University, University of North Carolina at Chapel Hill, and Duke University), one national laboratory (National Exposure Research Laboratory, U.S. Environmental Protection Agency), one State of North Carolina Department (Division of Air Quality, and Division of Water Quality, NC Department of Environment and Natural Resources), and one private research organization (MCNC- North Carolina Supercomputing Center), developed a monitoring model based on 2 weeks intensive field sampling during both a warm and cool season for each of the operational technology sites. In additional the model includes comparative monitoring of conventional lagoon and spray-field sites (2 total). During this reporting period, four candidate EST sites (Project 1, in-ground ambient temperature anaerobic digester/energy recovery/greenhouse vegetable production system; Project 10, solid separation/ reciprocating water technology; Project 7, belt system; and Project 3, solid separation/ constructed wetlands)

were evaluated during two seasons (cold and warm), and the results compared and contrasted with current lagoon and spray technologies at the 2 conventional swine farms. Data recently published shows that targeted emissions (odor, pathogens, and ammonia) were reduced under some of the environmental conditions studied for the candidate technologies.

Status of Economic Feasibility Analysis

The economic feasibility analysis of candidate EST involves determining the consequences of adopting the new technologies on the economic welfare of North Carolina citizens. Toward that end, the investigators (RTI International and NCSU Department of Agricultural and Resource Economics) are assessing the following general research objectives for this initiative:

1. Quantify the costs to farmers of adopting an identified set of alternatives to the current lagoon and spray field system.
2. Identify, assess, and describe financial and other logistical factors that will affect the technology adoption decision.
3. Estimate the effect of alternative technologies on the position of North Carolina hog and pork producers relative to competing producers in regional, national, and global commodity markets.
4. Identify and quantify the pathways by which the adoption of new waste management technologies changes pollutant emissions to air and water and affects environmental quality.
5. Estimate the monetized benefits to North Carolina households of the changes in environmental quality achieved by implementing alternative waste management technologies.

During the past year, construction and operation costs data were procured for:

(Project 1) Ambient Digester / Greenhouse tomato production,
(Project 3) Constructed wetlands,
(Project 5) Upflow biofilter,
(Project 10) Reciprocating wetland,
(Project 6) Super Soil Systems,
(Project 7) Belt Manure / Gasification System (belt component only),
(Projects 9 & 12) Belt Manure System / Manure Conversion to Insect Biomass,
(Project 16) Solids Separation / Ash Recovery,
(Project 11) Microturbine Co-Generation, and
(Project 14) Mesophilic Digester / Permeable cover.

Preliminary cost data for Projects 1, 3, 5, and 10 was published in the referenced Year 3 progress report.

RTI made substantive progress during the past year towards completing the development, testing, and evaluation of preliminary results of component models for measuring environmental impacts and assessing economic benefits. Specifically, a protocol and structure for integrating the different components of the environmental modeling and benefit assessment tasks into an

integrated benefits assessment tool was developed. This involved completion and testing of an ammonia dispersion and deposition model as well as a surface water model; analysis of groundwater data to explore the observed relationship between nitrate levels and local nitrogen loadings from hog farms; and development of a methodology for extending the ammonia dispersion model to estimate the impacts of ammonia emissions on regional ambient levels of particulate matter (PM). In addition, RTI completed the development and testing of the benefit transfer model (based on an existing hedonic property value study) for assessing benefits of odor reductions; continued the adaptation and re-estimation of the recreation demand model for assessing the benefits of improved surface water quality, and adapted an existing EPA benefit transfer model to assess the health-related benefits associated with reductions in ambient PM levels. RTI also made significant progress in designing and programming an integrated benefits assessment tool (IBAT), which combines the modeling components described above into a single integrated software system. IBAT is designed to include a user interface that will allow the user to define scenarios (i.e., reductions in releases from hog farms) and generate summary benefits assessment results. And finally, during the past year, RTI conducted a survey of North Carolina swine farmers to evaluate their perceptions on alternatives to the current lagoon and spray-field system. The completed survey and a comprehensive description of the benefits modeling activities described above are presented in the referenced Year 3 progress report (Williams, 2003).

SUMMARY

The sustainability of animal production agriculture will likely depend upon the development and implementation of manure management technologies that are capable of addressing environmental concerns associated with emissions from concentrated animal feeding operations. Technologies that range from simple to complex are under development in North Carolina and elsewhere that may address the concerns noted. In North Carolina, a major initiative funded by resources from Agreements between the NC Attorney General and Smithfield Foods, Premium Standard Farms, and Frontline Farmers is in progress to determine the technical, operational, and economic feasibility for approximately 18 candidate technologies. It is anticipated that such determinations will be completed for approximately half of the candidate technologies by mid 2004 and the remaining ones completed by end of 2005.

REFERENCES

Burton, C.H. (Ed.) 1997. Manure Management – Treatment Strategies for Sustainable Agriculture. Published by Silsoe Research Institute, Wrest Park, Silsoe, Bedford, UK.

Williams, C.M. 2002. Development of Environmentally Superior Technologies: Two-Year Progress Report for Technology Determinations per Agreements Between the Attorney General of North Carolina and Smithfield Foods and Premium Standard Farms, and Frontline Farmers (North Carolina State University Animal and Poultry Waste Management Center, on file with C.M. Williams; also available at www.cals.ncsu.edu/waste_mgt/).

Williams, C.M. 2003. Development of Environmentally Superior Technologies: Year 3 Progress Report for Technology Determinations per Agreements Between the Attorney General of North Carolina and Smithfield Foods and Premium Standard Farms, and Frontline Farmers. Reporting Period July 26, 2002-July 25, 2003. (North Carolina State University Animal and Poultry Waste Management Center, on file with C.M. Williams; also available at www.cals.ncsu.edu/waste_mgt/).

COMPOSTING SWINE MANURE AS AN ALTERNATIVE BEST MANAGEMENT PRACTICE

LUW Team – Livestock and Urban Waste Recycling Research Team

INTRODUCTION

Animal waste management has been and continues to be a growing environmental issue. The estimated useable amount of manure produced by confined animals (swine included) is more than 61 million tons per year (Sutton, 1996). As swine concentration and farm proximity to urban areas continues to increase concerns about the management of manure, also, continues to increase. If it is properly distributed and used on crop land as a soil amendment, manure can decrease commercial fertilizer costs substantially. Total potential manure fertilizer value from all livestock and poultry production in the U.S. has been estimated to value $3.4 billion annually (Sutton, 1996). However, potential for environmental pollution (including odor, nitrate and phosphorous) associated with direct land application of manure has heightened both the producers and the publics interest in alternative manure management strategies.

Accordingly, the Livestock and Urban Waste Recycling Research (LUW) Team has conducted several studies exploring composting as an alternative to direct land application of swine waste. Composting is an age old practice of waste management whereby the organic components of various waste streams are biologically decomposed under controlled conditions to a stabilized state in which they can be safely handled, stored or applied to land as a soil amendment. Composting can occur in the presence of oxygen referred to as aerobic composting or in the absence of oxygen referred to as anaerobic composting.

Most modern compost systems are aerobic for several reasons. One, the aerobic composting process is generally free from objectionable odor. Two, aerobic composting can inactivate pathogens and weed seeds. Three, the process is inexpensive and requires little technological input.

There are three primary methods utilized for aerobic composting – in vessel, static pile and windrow. Of the three methods, the windrow method is generally considered the most cost effective.

OBJECTIVES

The objectives of these studies were to:

1. Evaluate the use of swine waste and agronomic carbon sources as raw materials for composting.
2. Evaluate the use of swine waste and urban waste carbon sources as raw material for composting.
3. Clarify the effects of the resulting compost on soil parameters, crop growth, grain yield and potential transfer of pathogens from raw wastes through the composting process and soil application to the resulting grain.
4. Assess the horticulture industry in Illinois as a potential value-added market for compost.

5. Identify potential end users for compost and the characteristics they value for compost.
6. Develop and commercialize a value-added compost product that can be available for access by any Illinois composter and /or that can serve as a model for private sector entrepreneurs in the retail sale of compost.
7. Transfer of composting technology to Illinois farmers for adoption as a manure management alternative.

PROCEDURES

Compost Production:
An Illinois Environmental Protection Agency (IEPA) compost site was established on the Illinois State University (ISU) Farm-Normal in 1993. The site consists of 12.5 acres and produces approximately 4500 tons of finished compost annually. Numerous rows of swine slurry and various sources of carbon were developed to produce compost. Swine slurry was combined with woodchips, sawdust, cornstalks, wheat straw, grass clippings and yard waste.

Agronomic Trials:
Two agronomic plots were established on the ISU Farm-Normal. One was established in 1994 and consists of a 5 ha field site. The field site has uniform soil (Flanagan silt loam), with a 1 to 2% slope, good drainage, soil pH of 6.8, organic matter content of 3.5 to 4% and good fertility. To elucidate the effect of compost, seven treatments are being evaluated: 0, 11.2, 22.4, 33.6, and 44.8 Mg ha $^{-1}$ (0, 5, 10, 15 and 20 T:ac) of compost, 44.8 Mg ha^{-1} (20T:ac) of raw manure and 140 kg N ha^{-1} (125 lb:ac inorganic nitrogen). This plot has been planted into maize and soybean in alternating years. At physiological maturity, total above ground plant fresh weight and dry weight have been determined.

A soil sample was taken from each plot initially and is taken yearly for analysis of total element concentrations and content. Elemental concentrations and content have been determined for total N, P, K, Mg, Ca, S, Na, Cu, Mn, Fe, Zn, and B. Grain productivity has been estimated at physiological maturity (R6) and harvest maturity via plot combine. An experimental unit consists of 9.2m (twelve 76 cm rows) by 30.5 m in length. Each treatment is replicated three times, utilizing a randomized complete block design (RCB). Data derived from the field experiment has been analyzed utilizing a randomized complete block analysis of variance (ANOVA). Treatment means have been compared by calculating Fisher's protected least significant difference (FLSD) at the 0.05 probability level.

A second plot was established in 1996 and consists of a 5 ha field site. The field site has uniform soil, with a 1 to 2% slope, good drainage, soil pH of 6.8, organic matter content of 3.55, and good fertility. To elucidate the effect of compost, seven treatments have been evaluated; 0, 10, 20, 30, and 120 Mg ha^{-1}(0, 10, 20, 30, 60T:ac) of composted livestock waste, 120 Mg ha $^{-1}$(60T:ac) of "raw" uncomposted manure; and 180 kg ha^{-1}(160lb:ac) fertilizer nitrogen as a control. The 120 Mg ha^{-1} rate of composted livestock waste has provided an equivalent amount of nitrogen as the fertilizer nitrogen treatment. The experiment has been planted into maize and soybean in alternating years. To monitor maize at physiological maturity, total above ground plant fresh weight and dry weight has been determined. A sub-sample has been taken from each plot and analyzed for nutrient

concentrations and content for each sampling date. Grain productivity has been estimated at physiological maturity (R6) and at harvest maturity (R8) by combining the center four rows of each plot. An experimental unit consists of 9.2 m (twelve 76 cm rows) by 22.9m in length. Each treatment is replicated four times, utilizing a randomized complete block design (RCB). Data derived from the field experiment has been analyzed utilizing a randomized complete block analysis of variance (ANOVA). Treatment means have been compared by calculating Fisher's protected lest significant difference (FLSD) at the probability level.

Microbiological Analyses:
Several analyses were conducted to determine pathogenic indicator microorganism presence in raw slurry, compost, soil amended with compost or raw slurry, vegetative growth on soils amended with compost or slurry and seed grain produced from plants grown in soils amended with compost or raw slurry.

Methods used for microbiological analyses are described in Standard Methods for Examination of Water and Wastewater, 20th Edition (1995) with modifications for extraction of bacteria from solids and suspension of bacteria in fluid as follows (Kelley et. al., 1994; Kelley et. al., 1995):Ten-gram (g) samples were weighed and transferred to sterile 8-ounce Ball® canning jars (Allistar Corp. Munci, IN). Twenty to thirty-milliliters (ml) of sterile 1.0% buffered-peptone-water was added, and jars were capped with sterile blender blade assembly caps (Sunbeam/Oster, Schaumburg, IL). This mixture was blended for 30 seconds at high speed (approximately 15,000 revolutions per minute {rpm} using an Oster® blender to suspend bacteria in solution. The buffered-peptone0water solution acted both as a surfactant to remove bacteria from particle surfaces and to provide a nutritive medium prior to transfer to culture media. This method of mixing was determined in previous research studies to be optimal for removal of bacteria from the surface of animal waste and soil samples (Kelley et. al, 1994; Kelley et. al., 1995). The sediment was allowed to settle for approximately five minutes, and aliquots of the supernatant transferred directly to culture media, or 99.0-ml dilution blanks. Full strength aliquots and appropriate dilutions of replicates of each sample analyzed were plated in duplicate. A membrane filtration technique was used for coliform and Enterococci (Standard Methods, 1995). Appropriate aliquot volumes was transferred to the surface of sterile 0.45 micrometer (μm) pre size, 47 millimeter (mm) sterile polycarbonate gridded filters (Micron Separations Inc., Westborough, MA) in a Nalgene® filtration apparatus (Nalgene Co., Rochester, NY.). Fluid samples were drawn through the filter by partial vacuum, the funnel rinsed with sterile 0.1% peptone-water to remove adhering surface bacteria, and filters transferred aseptically to the surface of appropriate sterile agar culture media (Difco Laboratories, Detroit, MI) in 50-mm Petri dishes (Fisher Scientific, Pittsburgh, PA). Appropriate culture media was used for isolation and enumeration of total coliform, fecal coliform, and Enterococci, respectively. Petri dishes were inverted and transferred to incubators for incubation at appropriate temperatures for appropriate time periods (Standard Methods, 1995). Concentrations of Staphylococci and heterotrophic bacteria were determined using a spread-plate technique (20). Fluid aliquots of 0.1 ml of appropriate dilutions were transferred to the surface of mannitol-slat agar or plate count agar in 100-mm Petri dishes. Fluid samples were spread evenly on the agar surface using a sterile glass spreader. Transfer to other selective or confirmatory media was made as necessary, characteristic colonies were enumerated and results reported on a cfu g^{-1} dry

weight basis. Samples of approximately 10-g were dried at 103°C for four hours to determine moisture content of samples analyzed. Data generated were subjected to paired t-test analysis to compare effluent, compost, soil, water and vegetative bacterial concentrations, and significance determined and reported at $p<.05$ and .01 levels.

RESULTS AND DISCUSSION

Compost Production:

The secret to successful aerobic composting is the speed at which raw materials breakdown and the quality of the compost ultimately produced. The most important factors in achieving both requirements are moisture content, carbon to nitrogen ratio of the raw materials, and the temperature achieved during the composting process (Anonymous, 1991). In practice, the moisture content of composting material should not be allowed to drop below 45 to 50 percent, nor should it be allowed to rise above 65 to 70 percent. Another important factor in composting is the carbon to nitrogen ratio. Initial mixtures of raw material prior to composting should have carbon to nitrogen ratios ranging between 25:1 and 30:1. A check of carbon to nitrogen ratios will help determine what combination of raw materials is suitable for composting.

This study evaluated two types of swine manure (solids scraped from concrete lots housing gestation sows and commingled gestation, lactation, nursery, grow-finish slurry collected from an eight foot deep pit) and evaluated several types of carbon sources i.e. corn stalks, wood chips, sawdust, yard waste/grass clippings and county fair waste consisting primarily of undetermined amounts of wood shavings and wheat straw. Table 1 provides the selected fractionate analyses of the raw manure and carbon sources. Several points are worthy of mention regarding the analyses of the manures. One, the "solid" manures generally contain around 50% moisture and the slurries contain 90+% moisture. The high moisture contents infer that the moisture content will effect the proportion of raw materials blended more than the C:N ratio as a 50% moisture content will be reached before a 25:1, C:N ratio will be reached. Consequently, manure may require addition over time until an appropriate C:N ratio is reached that will result in complete composting of the carbon and nitrogen sources. Leaves, wood chips and corn stalks are similar in nitrogen content. Grass and yard waste are relatively high in percent nitrogen, supporting data that very little manure can be blended with grass for composting without lowering the C:N ration below desired levels. Sodium concentration in the carbon sources is relatively low.

Table 2 contains interesting data. Lowering the carbon:nitrogen ration from 30:1 to 25:1 increases the amount of manure that can be blended with a carbon source several fold. However, maintaining moisture content of 50% appears to be a greater limiting factor effecting the amount of manure that can be blended with a carbon source. Actual combinations achieved during production scale operations were closer to the limiting theoretical moisture combinations than to theoretical C:N ratios. Corn stalks, woodchips and sawdust were identified as carbon sources that can accept the greatest amount of manure, especially when slurry is the nitrogen source.

Table 3 shows the percent yield of compost produced from various combinations of raw material. Blends of raw material containing carbon sources with higher nitrogen contents i.e.

grass and county fair waste had higher yields and lower percentage reduction in weight (volume) loss. Percentage yield of other combinations were similar. In general, combinations of manure and carbon sources have a reduction in weight (volume) around 65% and yield approximately 35% of the original weight as compost. Several studies (Rynk, 1992) suggested the reduction in volume/weight is around 50% but this data suggests that when using swine manure particularly slurry as the nitrogen source the reduction may be much higher. The greater loss in volume/weight infers that less material (manure) must be hauled from the compost site to the field selected for land application.

Tables 4 and 5 show the selected analyses performed on finished compost. An important observation to note is that physical appearance of compost alone is not necessarily indicative of quality. From a physical appearance perspective all of the compost analyzed possessed an acceptable consistency and physical structure. Most of the characteristics analyzed were found within acceptable ranges. Exceptions that should be noticed include: sodium concentration, seed germination, ammonia concentration, C:N ratio and conductivity. Livestock manure (especially swine manure) can be relatively high in sodium. High sodium concentrations can negatively effect seed germination rates. High ammonia concentrations coupled with high C:N ratios can suggest the compost analyzed had not sufficiently cured to insure optimum stability; or that too much manure was added relative to the amount of carbon provided. In these cases the latter is the most likely cause of higher than desired ammonia concentrations. Other fractionates selected for analysis appeared unaffected by the raw materials selected to produce compost. Nitrite levels, sulfide levels, humus, pH and moisture content were all found within acceptable ranges.

Moisture content of the raw materials may be the greatest limiting factor affecting the amount of livestock manure that can be combined with a carbon source to produce compost (Walker, et. al., 2000). Composting reduces the amount of raw material by about 2/3's, yielding about 35% of the original raw material weight as compost. Sodium concentration in livestock manure can result in compost with sodium concentrations too high for some uses such as potting mixes.

Physical appearance of compost alone is not indicative of high quality compost. Choice of raw materials for composting is not as important as the composting process utilized for producing high quality compost. Leaves produce a more attractive compost in physical appearance compared to woodchips but a given unit volume (weight) of woodchips can accept a greater unit volume (weight) of livestock manure that other carbon sources. Sawdust can be combined with the greatest amount manure and still maintain an acceptable C:N ratio. The primary disadvantage for using sawdust is that it requires about 12 months to completely compost and to produce "cured" finished compost compared to 8-12 weeks for the other carbon sources.

The carbon source selected to produce compost may depend on several factors including availability, cost (or revenue received) and purpose for composting. Obviously a producer will choose to use carbon sources that are local and carbon sources that are either free or for which the producer receives a tipping fee to accept. In addition, the reason for composting may determine which carbon source is preferred. Woodchips and sawdust (because of their

high carbon content) require more nitrogen (manure) to completely compost. If the producer is composting as an alternative manure handling practice and is using the compost as an on-farm soil amendment; the length of time (longer time) required for composting may not be as important as the total amount of manure that can be composted. On the other hand, if the objective is to achieve the greatest economic return from marketing compost then shorter composting times will be more important and leaves, corn stalks or grass may be the preferred carbon resources. An important negative aspect for composting grass, is that prior to composting grass has a substantial odor and must be aerated (turned) frequently to control the odor.

Several factors affect the cost of producing compost including type of equipment, source of carbon, amount of compost produced, quality of compost produced and cost of labor. The minimum equipment required to produce compost is a typical rear discharge or side discharge manure spreader and a tractor equipped with a front end loader. More elaborate equipment can be utilized, and as the kind and type of equipment used increases so does the cost. However, to produce higher quality, value-added compost more equipment may be required such as a compost turner, a screener and a tractor capable of traveling as slow as .1 mph at PTO speed (1500-2000 RPM). As example, equipment utilized at the Illinois State University Farm Compost Site includes:

ISU Farm Compost Site Equipment Cost

Equipment	Cost
85 hp tractor with creeper gear and loader	$44,425
100 hp tractor	$40,000
side discharge spreader (212 cu. Ft. capacity)	$15,135
rear discharge spreader (206 cu.ft. capacity)	$11,128
compost turner	$25,000
slurry tank (2250 gal. capacity)	$20,000
compost screener	$35,000
total equipment cost	$190,000
Annual equipment expense (depreciated over 10 years at 10% interest with no salvage value)	$31,035

Annual Charges For Composting At The ISU Farm

Item	Amount
Land (12.5 acres @ $100:acre rent)	$ 1,250
Equipment	$31,035
Repairs	$ 2,000
Fuel	$12,480
Labor	$32,462
	$79,225

The equipment charges used for these calculations are the purchase cost of new equipment. The labor charge is for one full time civil service position. Equipment costs could be lower for the same equipment purchased as used equipment and labor may be valued either higher or lower. The cost of producing compost during the first two years of production at ISU was $31.69 per ton when the site produced 2500 tons:year of finished compost. Currently the cost of producing one ton of compost at ISU is $17.60 because the site is producing 4500 tons:year. Actually, the cost of producing compost at the ISU Farm Compost Site is only $12.60:ton when the tipping fee for accepting the landscape waste is considered. The ISU Farm Compost Site receives a tipping fee that equates to approximately $2:cu.yd. of landscape waste ($5:ton of finished compost) received as revenue, which when subtracted from the $17.60 cost:ton of production equates to $12.60 cost:ton of compost. Depending on quality, ISU compost is currently selling for $10 to $40 per ton in bulk. Bagged compost (40 lb:bag) is selling for $2.50:bag, which equates to $125:ton.

Agronomic and Microbiological Analyses:

These studies observed that compost can be used as a soil amendment and as a substitute for nitrogen fertilizer (Smiciklas, et. al., 1997). Growth and development of corn plants supplied with high rates of mature compost was similar to corn supplied with fertilizer N. Growth and development of corn plants supplied with uncomposted manure (slurry) was somewhat inferior to corn plants supplied with high rates of compost or fertilizer N. The use of mature compost did not alter most measured soil parameters of higher organic matter soils one to five years after application, regardless of the rate of application. Concentrations of indicator microorganisms were absent or below minimum detection levels in soil and corn grain samples where compost was applied suggesting no transfer of pathogens from manure . Neither were concentrations of indicator microorganisms detected in corn grain samples produced on soils amended with raw manure (slurry). The implications of these observations are very important, reinforcing the concept that manure can be used safely as a soil amendment for grain production (Kelley et al, 1999, Kelley et al, 1999). Very high rates of compost and raw manure (60 tons:ac, dry matter basis) increased fertility of the soil as measured by organic matter percent but, also, significantly increased the potassium (K) and phosphorous (P) concentrations. Additional data is needed to assess seasonal variation and long term effects of compost amendment on soil and ground water.

Table 6 shows the corn and soybean yields as effected by amending the soil with compost. Similar corn grain yields were observed by applying the equivalent of 20,30 or 60 dry tons of compost. The data suggests there is little benefit on higher organic matter soils to apply more that 30 dry tons of compost per acre. Higher application rates of compost (20, 30, or 60 tons:ac) out yielded ($p<0.05$) inorganic nitrogen fertilization. Regarding soybean yield, compost application and fertilizer addition had less effect on yield compared to corn yield, as should be expected. On higher organic matter soils, soybeans should be expected to fix satisfactory amounts of nitrogen to obtain optimum yields. Compost amendment, regardless of application rate increased soybean yield compared to zero fertilizer or 150 pounds of inorganic N fertilization.

Market Development and Technology Transfer:
Focus Group Session
As part of our market development activity for compost the LUW Team hosted a focus group meeting. Several (23) prominent Landscape/Nursery businesses in the Bloomington/Normal and Peoria area were invited to share their opinions regarding the use of compost in their specific operations. In order to help composters produce higher quality compost we asked participants to respond in group discussion to the following questions.

- Have you ever used compost or compost based products?
- What products do you view as being interchangeable with compost?
- What are your potential uses for compost?
- What characteristics must compost contain for you to use compost?
- What do you consider are the positive aspects of compost?
- What do you consider are the negative aspects of compost?
- How much (volume/weight) compost could your operation utilize?
- When (what time of year/season) would your operation require compost?

Spent mushroom strata, hardwood chips and pine chips were cited as the primary substitutes or competing replacement materials for compost. The disadvantages provided by participants for these substitute products were their low fertility value (woodchips) and high, almost toxic, sulfate/salt content (mushroom strata). Those products cited as most often used in place of compost were peat moss, top soil, manure and mushroom "compost" (spent mushroom strata).

The participants noted several potential advantages for using compost including, nutrient content and improved fertility value compared to "so-called" top soil. Most participants expressed dissatisfaction with the quality of top soil they were using. There were several reasons provided regarding why compost was not used. Primary reasons given were lack of knowledge regarding compost and a previous bad experience from using low-quality compost. Several criteria were provided that compost producers must address if they are going to enter the retail market for compost. Of major importance is price. Compost must be competitively priced with peat moss and woodchips. Compost producers must be able to supply ample quantities of compost when retailers/endusers need it i.e. during the months of April, May, June and September. A general consensus was that nurseries and retail outlets could use bulk deliveries of compost for their own use but compost producers should be prepared to bag compost for retail sales. Bags are the preferred container of choice.

MANURE COMPOST WORKSHOPS

Five compost workshops were held in Central Illinois. The primary target audience for these workshops were farmers with a true interest in starting compost sites of their own. Attendees at these workshops ranged from 15 to 150 persons. We are currently aware of 15 farmers in Illinois who are composting livestock manure whether for their own use or for retail sale.

Two survey members of four Illinois professional horticulture organizations were conducted to document specific quality concerns of potential retail market end-users about compost. This report was completed to provide a basis from which stakeholders can one, develop compost

plans and two, initiate compost market expansion programs. A complete summary of these surveys is reported in the "Illinois Statewide Compost Market Assessment" (2001) that is available online at http:www.cst.ilstu.edu/ksmick/compost/agcover.htm.

A majority of the survey participants who responded to the survey either have in the past or currently use compost. While use as a soil amendment or conditioner was reported as the most frequent use, additional information may be required to determine who uses and what the current uses are for compost. This survey suggested soil tilth and accelerated plant growth were perceived as primary benefits for using compost. Consistency of quality and freedom from disease-bearing and parasitic organisms were of greatest concern to the purchasers of compost in this survey. In addition, the cost:quality relationship of compost was rated as a major concern among current users of compost. The development of quality standards for compost was considered important by those who use compost but was not found to serve as a stimulus to encourage use of compost by non-users.

Probably the greatest barrier to the development of a successful compost marketing program is compost quality. Producing a product which meets the requirements for specific end users is critical, also.

Compost producers must look upon themselves as product manufacturers and not waste managers. This mindset affects not only product quality, but also efforts invested into market development. Aside from product quality, probably the greatest reason for compost marketing failures is simply a lack of effort and investment in the marketing arena. Although primary marketing efforts must be completed by compost producers themselves, the Illinois Department of Commerce and Community Affairs, perhaps through the Bureau of Energy and Recycling, can assist the compost industry in market development. A concerted and coordinated effort is needed to educate homeowners and the green industry about compost. This is a role DCCA could provide in cooperation with the Illinois Department of Agriculture and the University of Illinois Extension Program.

MARKET DEVELOPMENT

The "Illinois Statewide Compost Market Compost Assessment" reports that the potential market for compost in Illinois surpasses 1.8 million tons annually. In order for swine producers to tap into this potential value-added market brand name recognition of one or more compost products is necessary. Accordingly, a branded compost with specific standards was developed. This product is referred to as Sweet Earth. Any producer of compost can market compost under the Sweet Earth brand name if the compost quality can be verified by laboratory analyses. The quality of standards of each ton of compost marketed as Sweet Earth must be verifiable by a laboratory analysis (Table 7). A royalty also must be paid to the Illinois State University Department of Agriculture a the rate of $.05 per 40 pounds sold i.e. 5¢:40 lb bag or $2.50:bulk ton. Access to this brand name product should facilitate market access for smaller scale producers of compost.

COOPERATOR SITES

The objective of this portion of the project was to establish farmer operated compost sites that can serve as demonstration/evaluation sites in local communities throughout the state of Illinois. Funding purchased four compost turners and three specialized tractors to pull the turners. Tractors that pull turners must be capable of traveling as slow as .1MPH. The used tractors purchased are equipped with a hydrostat transmission.

Four farmers were identified who had a desire to participate in the project. Assistance was provided to each farmer in developing a compost site, obtaining one or more carbon sources and initiating a compost operation. Equipment (one turner and/or one tractor) is provided to each cooperator for a two year period. At the end of the two year period the cooperator must purchase a turner and tractor if the compost operation is to continue. The university owned tractor and turner are then loaned to another cooperating farmer to establish another compost site. Of the four sites established, two will continue for one more year as part of the project and two will continue as private ventures. Two additional cooperators have been identified who will begin composting with university owned equipment during the fall of 2003. Each site is expected to host a compost-manure management field day during year two of operation with assistance from the LUW Team. The four established compost sites are: Merna Farms, Merna; Alan Dale Farm, Walnut; Dumoulin Swine Farms, Hampshire; and QW Farms, Edgewood.

Development of Alan Dale Compost Site
With the assistance of the LUW Team, this site received an IEPA compost siting permit during 2001. This permit allows compost produced at this site to be marketed for off-farm use.

Alan Dale is a row crop farmer, farming approximately 1,700 acres of primarily corn and soybeans. Mr. Dale does not operate a livestock enterprise. He is utilizing livestock waste (especially swine slurry) generated by his neighbors and both agronomic carbon sources (old large round hay and straw bales; chopped corn stalks; etc.) and urban carbon sources (woodchips and leaves) as raw materials for composting.

The goal of Alan Dale is to produce value-added designer compost for retail sale. A brand name compost has been developed specifically for marketing by his compost operation called "Rare Earth". The composting procedure used at this site will follow the "recipe" method. Producing compost according to a recipe involves using multiple sources of raw carbon material and raw nitrogen material in addition to fine clay earth, bacteria innoculant and the use of windrow covers to aid in the control of windrow moisture.

Development of Alan Dale Compost Site
With the assistance of the LUW Team, this site received an IEPA compost siting permit during 2001. This permit allows compost produced at this site to be marketed for off-farm use.

An agreement was developed with the town of Princeton. Accordingly, Princeton Public Works Department will provide leaves collected each fall for a tipping fee (approximately equivalent to $2:cubic yard) payable to Alan Dale. These leaves will serve as a carbon source and will provide off-farm revenue to support operation of the compost site. This is a win-win scenario for both

the agriculture community (represented by Alan Dale) and the urban community (represented by citizens of Princeton). Previously Princeton burned the leaves, a process that resulted in substantial residential complaints about air pollution.

Development of Merna Farms Compost Site

This site was developed during July 2001. This site was developed to provide an alternative liquid manure management handling strategy during those times of the year when all available crop land for manure application is unavailable, thereby, allowing the operation to maintain the legal free board depth in the operations slurry storage tank.

This operation applies all compost that is produced to farm land operated by Merna Farms as a soil amendment for corn and soybean production. Merna Farms operated approximately 500 acres in corn and soybean production and maintains 4-1,100 head confinement finishing buildings marketing approximately 10,000 head of hogs per year and generating about one million gallons of slurry each year.

The primary method for disposing of swine slurry in the past at this farm had been and will continue to be in the future field injection. Composting will serve as an alternative manure handling strategy to keep the operation in compliance with the IEPA and the Livestock Management Facilities Act. The Merna Farm goal at the present time is not to produce designer, value-added compost for the retail market. Therefore, this composting operation does not utilize the "recipe" method for producing compost. The compost site accepts wood chips and leaves. The wood chips are produced from brush generated by the City of Bloomington and processed by Twin City Wood Recycling. Twin City Wood Recycling grinds the brush and delivers wood chips to the compost site. Leaves are delivered to the site by the Bloomington Public Works Department. Liquid swine manure is added to the wood chips and leaves at a rate of less than 10% by volume.

Development of the Dumoulin Compost Site

Dumoulin Swine Farms is operated by the Dumoulin family and consists of 700 acres in corn and soybean production, and 1,200 sows in a farrowing to finish operation, producing 25,000 market hogs and generating 2.4 million gallons of slurry annually. This family farm is located near Hampshire, IL in Kane County. This compost site was established in December 2001. The goal is to utilize horse bedding (straw and wood shavings) and landscape waste provided by waste haulers serving the collar counties of the Chicago area. Dumoulin Farms will receive a tipping fee averaging $1:cubic yard of bedding /landscape waste delivered to their compost site. Swine slurry will serve as a nitrogen source to mix with the horse bedding and landscape waste. The Dumoulin's are trying to compost one million plus gallons of slurry each year.

Development of the Q-W Farms Compost Site

Gerald Quade and Wayne Willenburg operate Q-W Farms in Effingham County near Edgewood. They generate about 1 million gallons of slurry each year. They are utilizing waste sawdust from a nearby sawmill as their carbon source. Their goal is to utilize compost as an alternative manure handling practice and to apply the compost as a soil amendment for row crop production on their farms. Since the fields located near the swine buildings have high phosphorous concentrations, they plan to haul the compost to more distant fields for application. This site was established during the winter of 2003.

CONCLUSION

Small, medium and large scale swine producers should find the implications of these studies particularly useful. A variety of carbon sources can be utilized for composting either solid or liquid manure. A brand name compost has been developed that can be used by Illinois swine producers to assist them in value-added marketing of their compost. Several cooperator compost sites have been developed that are being used as demonstration sites in designed locales to advance the concept of composting. An in depth compost market analysis has been conducted for Illinois and is available to swine producers interested in developing a compost operation and marketing compost as a value-added product. Composting is a practical, economical and environmentally safe way for pork producers to co-exist with increasing urban sprawl regarding the utilization of swine manure.

COMPOSTING SWINE MANURE BULLET POINTS

- During composting manure is considered a nitrogen source and requires mixing with a carbon source such as straws, corn stalks or landscape waste.
- Solid and liquid swine manure can be composted with success.
- Composting can be utilized as a manure management practice by small, medium and large scale operations.
- Corn and soybeans grown on soils amended with compost yield similarly to crops grown with inorganic fertilizer.
- Composting reduces the volume of manure that must be land applied.
- Composting can inactivate pathogenic microorganisms.
- Cost to compost is dependent on several factors and cost of production can range between $10.00 and $32.00 per ton.
- On average 1 pound of manure must be mixed with 1 pound of carbon source, but the mixture can range between .54:1 to 3.5:1, manure:carbon source, depending on the type of manure and type of carbon source.
- On average two pounds of raw material (manure + carbon source) produces one pound of cured compost.
- Compost can be used on-farm as a soil amendment or can be sold off-farm as a value-added product.
- Prices for compost range between $10:ton and $200:ton depending on quality of compost.

TABLE 1. SELECTED FRACTIONATE ANALYSIS OF CARBON SOURCES AND MANURE TYPES

Type of Waste	pH	DM	Ash	C	N	P	Ca	Al	Cu	Fe	Mg	Zn	Co	Cr	Mn	Ni	K	Na	C:N
				%									ppm						
Leaves	6.3	87.2	13.0	49.5	1.3	.14	2.25	820	4801	3901	390	700	400	700	240	200	2050	550	39
SD	08	7.9	8.3	1.9	.1	.05	068	540	370	1740	1080	400	500	130	110	100	2030	330	3
N	17	12	12	12	8	10	10	10	10	10	10	10	10	10	10	10	10	10	8
Grass	7.0	58.4	20.8	44.0	3.8	.02	.17	515	280	220	1590	270	55	370	795	170	3950	430	12
SD	.7	12.6	8.3	4.6	.6	.01	.14	445	354	2078	1230	296	77	268	372	85	4030	113	1
N	6	8	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Woodchips	7.2	86.0	12.7	48.5	1.1	.08	1.0	1552	135	2519	2060	144	141	230	183	120	3450	1670	45
SD	.7	5.7	3.1	1.7	.2	.03	.7	591	29	598	70	219	279	24	157	120	2390	2390	6
N	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Corn stalks		90	8.0	51.1	06	1.3	.05	323	48	776	1227	40	2	BD	50	BD	6086	150	86
SD		2.5	2.0	2.3	.2	.04	.05	32	8	76	122	4	1		5		86	15	
N		10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Swine Slurry	6.9				2.22	.61	.10	368	113	343	414	111	112	76	76	110	3018	1312	
SD	.2				1.9	.44	.07	376	136	222	405	39	127	39	75	89	1701	841	
N	.8				26	26	26	26	26	26	26	26	26	26	26	26	26	26	
Solid Manure	7.7	40.7	9.2	50.4	1.9	.24	.32	451	84	1192	1714	836	123	302	89	315	2986	1658	32
SD	.6	9.6	5.8	3.2	.7	.32	.33	327	96	511	485	243	162	540	101	451	2621	1338	10
N	26	25	22	22	27	18	22	22	22	22	22	22	22	22	22	22	22	22	22
Swine solids with bedding (straw & corn stalks)	7.8	51.6	24.3	42.1	2.2	.09	.11	60	18	10	480	30	14	18	26	14	176	355	20
SD	.4	20.9	9.5	5.3	.7	.09	.01	40	7	14	64	15	14	14	11	8	94	271	5
N	8	8	7	7	7	7	7	7											7

TABLE 2. TONS OF RAW MATERIAL REQUIRED TO PRODUCE ONE TON OF COMPOST

Raw Material	Theoretical C:N Ratio		Theoretical Moisture Combination	Actual Combination Achieved
	25:1	30:1	50% Moisture	
Solid Manure: Corn Stalks	19.9:1	10.6:1	5.7:1	.93:1
Slurry: Corn Stalks	60.7:1	46.3:1	1:1	1.1:1
Solid Manure: Leaves	3.7:1	1.31:1	6.1:1	2.6:1
Slurry Leaves	68.6:1	6.6:1	.82:1	.91:1
Slurry: Woodchips	17.1:1	10.3:1	.75:1	3.5:1
Slurry: Sawdust				2.3:1

TABLE 3. PERCENT YIELD AND REDUCTION OF RAW MATERIAL TO PRODUCE COMPOST

Raw Material	Nitrogen Source:Carbon Source (tons:tons)	Yield %	Reduction %
Slurry Grass	.54:1	47	53
Solid Manure/Grass	1.4:1	21	79
Solid Manure/Leaves	2.6:1	29	71
Slurry/Leaves	.91:1	34	66
Slurry/Corn Stalks	1.1:1	17	83
Solid Manure/Corn Stalks	.93:1	36	64
Slurry/Woodchips	3.5:1	23	77
Solid Manure[a]/Fair Waste[a]	.97:1	70	30
Solid Manure[a]/Yard Waste[b]	1.86:1	41	59
Slurry/Sawdust	2.30:1	20	80

[a] Fair waste refers to shavings, woodchips and straw waste generated by the McLean Co. Fair.
[b] Yard waste refers to mixtures containing varying amounts of grass, leaves and yard trimmings.

TABLE 4. MEAN SELECTED FRACTIONATE ANALYSIS OF COMPOST PRODUCED FROM VARIOUS RAW MATERIAL COMBINATIONS

Raw material	Ammonia (ppm)	Nitrites (ppm)	Nitrates (ppm)	Sodium (ppm)	Sulfate (ppm)	Sulfide (ppm)	Seed Germination %	Humus %	pH	Conductivity (Ergs)	Redox Potential	Moisture (%)	C:N	Physical Appearance[a]
Desired Level	<50	0	700-800	9-200	100-300	0	>70	>50	7.0-8.1	<3000	26.5-29	40-50	15-20:1	5
Slurry/Woodchips	45	0	810	202	218	0	84	56	8.2	2337	25.5	56	20:1	3
Slurry/Corn Stalks	84	1.7	587	2300	452	0	70	55	7.1	3053	25.1	44	16.5:1	4
Solid Manure/Cornstalks	51	0	320	200	113	1	60	75	8.2	1900	27.6	50	24.5:1	4
Solid Manure/YardWaste	62	0	418	203	44	1	70	65	8.0	2547	24	50	24:1	4
Slurry/Grass	57	0	75	97	46	0	90	62	8.0	3217	24	50	25:1	5
Solid Manure/Leaves	91	.63	449	746	256	.26	79	66	7.8	3344	24	35	16.2:1	5
Solid Manure/FairWaste	50	0	168	128	69	0	56	71	8.0	1810	25.7	50	25.1:1	5

[a] Physical appearance reflects visual observation scores on a scale of 1-5, where 1 is undesirable and 5 is desirable.

TABLE 5. MEAN SELECTED ELEMENT ANALYSIS OF COMPOST PRODUCED FROM VARIOUS RAW MATERIAL COMBINATIONS

Raw Material	N	P	K	Ca	Mg	Zn	Mn	Fe	Cu	B
	%					(ppm)				
Desired Level	.6-1.2	Varies according to agronomic need								
Slurry:Woodchips										
Mean	.91	.48	.79	3.47	1.02	2.65	675	6607	283	40
SD	.51	.27	.36	1.09	.26	103	214	1962	188	53
N	8	8	8	8	8	8	8	8	8	8
Slurry:Corn Stalks										
Mean	1.53	1.00	2.00	4.60	1.23	272	1481	21541	180	157
Solid Manure:Corn Stalks										
Mean	.50	.40	.70	4.50	1.90	378	854	6984	562	12
Solid Manure:Yard Waste										
Mean	.70	.40	1.00	4.43	1.30	260	700	5490	148	25
Solid Manure:Fair Waste										
Mean	.70	.50	.80	4.30	1.20	410	1123	11981	625	14
SD	.10	.10	.10	1.60	.6	297	572	7725	725	7
N	5	5	5	5	5	5	5	5	5	5

TABLE 6. GRAIN YIELD (BU:AC)

Treatment[a]	Corn Yield	Soybean Yield
0	142	54*
5 Compost	144	60
10 Compost	144	61
20 Compost	151*	63
30 Compost	158*	63
60 Compost	159*	63
60 Manure	157*	68
150 Nitrogen Fertilizer[b]	143	54*

[a]Dry matter basis tons:acre

[b] lbs:acre Means within a column with different superscripts differ significantly ($p<0.05$)

TABLE 7. TARGET STANDARDS FOR "SWEET EARTH" SWEET EARTH COMPOST

Criterion	Concentration Limits[a]
Fecal coliforms	≤1,000 cfu:g total solids
Salmonella	≤3 MPN:4g total solids
Arsenic	≤41 ppm
Cadnium	≤21 ppm
Chromium	≤1,200 ppm
Copper	≤1,500 ppm
Lead	≤300 ppm
Mercury	≤ 17 ppm
Nikel	≤420 ppm
Selenium	≤36 ppm
Zinc	≤2,800 ppm
PH	6.5-8.5
Germination	≥70%
Ammonia	≤50 ppm
Nitrates	≤800 ppm
Sulfates	≤90 ppm
Sulfides	0
Humus	≥40%
Conductivity	≤3,000 ergs
Redoxpotential	23.0-29.0
Nitrogen	.6-1.2%
Nitrites	0

[a] Dry matter basis

LITERATURE CITED

Anonymous. 1991. The Art and Science of Composting. Biocycle. J.G. Press, Inc. Emmaus, PA.

Kelley, T.R., Pancorbo, O., Merka, W., Thompson, S., Cabrera, M., Barnhart, H. 1994. Fate of selected bacterial pathogens and indicators in fractionated poultry litter during storage. J. Appl. Poul. Res. 3:279.

Kelley, T.R., Pancorbo, O., Merka, W., Thompson, S., Cabrera, M., Barnhart, H. 1995. Bacterial pathogens and indicators in poultry litter during re-utilization. J. Appl. Poul. Res 4:366.

Kelley, T.R., P.M. Walker and K.D. Smiciklas. 1999. Survival of culturable bacteria during co-composting of institutional, agricultural and municipal solid wastes. Environ. Pract. 1:162-167.

Kelley, T.R., P.M. Walker and T.R. Kelley. 1997. Transfer of indicator bacter and other bacteria from compost to soil and agronomic crops. Abst. Amer. Soc. Microbio. Chicago, IL.

LUW Team. 2001. Illinois Statewide Compost Market Assessment. IL State Univ. Normal, IL.

Smiciklas, K.D., P.M. Walker and T.R. Kelley. 1997. Utilization of compost in new crop production. Abst. Amer. Soc. Agron., Crop Sci., Soil Sci. 114.

Rynk, R. 1992. On-Farm Composting Handbook. Nat. Resource, Agri. and Eng. Ser. Coop Ext. Ithaca, N.Y.

Standard Methods for the Examination of Water and Wastewater, 19th Ed. 1995. American Public Health Assoc., American Water Works Assoc., Water Environment Federation.

Sutton, A.L. 1996 Animal Wastes A Growing Environmental Issue. News CAST. 23:004. 2-4.

Walker, P.M., T.R. Kelley, and K.D. Smiciklas. 2000. Composting as a viable alternative to traditional livestock disposal. Abst. J. Anim. Sci. 778. suppl. 2:40.

UTILIZING SOLID – LIQUID SEPARATION TECHNOLOGY FOR PROCESSING SWINE SLURRY

LUW Team – Livestock and Urban Waste Recycling Research Team

INTRODUCTION

Hundreds of millions of tonnes of swine waste are generated annually worldwide as a by-product of international pork production (Rhymer et al., 1995). During the late 20th Century, a shift occurred in the industry from more traditional, limited-confinement pork production techniques to swine confinement facility production in order to meet public demand for leaner pork and to minimize pork production costs. This shift increased swine waste "production concentration", or the amount of waste generated in a limited geographical area available for agricultural land application, referred to as "land-limited conditions". Therefore, swine waste production may exceed the capacity of the local or regional environment to properly assimilate this waste through agricultural land application and/or discharge to natural aquatic systems (Hatfield and Stewart, 1998).

Currently, swine waste management primarily consists of waste retention in pits, often followed by discharge to a lagoon system for stabilization (e.g., digestion of the settled solids). Increased swine production and encroachment of residential human populations into formerly rural areas has resulted in public opposition to lagoon treatment due to environmental degradation potential and aesthetic issues (e.g., accidental releases and off-odors). Failure of lagoon systems to adequately store or treat swine waste prior to discharge has led to environmental concerns in major pork-producing states including Illinois. Excessive land application of swine waste may also result in off-odors, runoff into surface water systems or degradation of soil-groundwater systems (Ritter and Chirnside, 1990, Burkholder et al., 1997; Haywood, 1997).

Swine waste slurry may be defined as a mixture of solid and liquid wastes with or without added water to facilitate movement (e.g., pumping or flushing). In order to treat swine waste more efficiently, economically, and responsibly, application of modified traditional waste-water treatment technologies to swine waste slurry may be feasible. Solids separation is a common primary wastewater treatment. Solids separation may include three steps: (1) chemical-aided coagulation, (2) mixing and resulting particle aggregation (flocculation), and (3) sedimentation of the flocculation product (floc) due to gravity or centrifugation (Hammer and Hammer, 2001).

Mechanical screening of animal wastes for solids separation was extensively researched from 1970-1990, focusing primarily on maximizing solids separation efficiency (Glerum et al., Graves and Clayton, 1972, Shutt et al., 1975 Shirley and Butchbaker, 1975 Rorick et al., 1980, Prince and Hill, 1985, Koegel et al., 1990). More recently, Hill and Baier (2000) and others have included the determination of chemical properties such as pH, chemical oxygen demand (COD), N, P and carbon (C). Application of belt presses, commonly used to separate biosolids from human waste, to the separation of other animal wastes has been less extensively investigated (Fernandes et al., 1988, Severin and Grethlein, 1996). This treatment often includes addition of polymeric compounds to facilitate biosolids dewatering (Hammer and Hammer, 2001).

Recent examples of modified or alternative wastewater treatment options evaluated to reduce solids and nutrient concentrations include solids separation and mixing processes (Koh et al., 1995), sequencing batch reactor fermentation (Lee et al., 1997), chemical coagulation (Tseng and Tsai, 1996; Ndegwa et al., 2001); and resulting flocculation (Buelna et al., 1990; Henriksen et al., 1998a, b), centrifugation (Sneath, 1988), and sedimentation (Martinez et al., 1995, Cullum, 1988). Improved swine slurry solids removal efficiency has been previously demonstrated through the addition of metallic salt chemical coagulants (Ndegwa et al., 2001). Solids separation also, may yield a value-added bioresource that may be used as a soil or compost amendment due to its retained nutrient content, reduced water content, and associated reduced weight and transport costs (Kelley et al., 1999; Ndegwa et al., 2001). Manure and compost have long been recognized as soil amendment bioresources, when properly managed (Hatfield and Stewart, 1998). Separated animal waste solids have been used as animal feed additives, although disinfection prior to feeding was found to be advisable (Fransen et al., 1995; Kelley and Walker, 2000).

Many of these alternative treatment options for swine waste were modified techniques used for municipal (human sewage) or industrial wastewaters. However, swine waste is typically produced in both higher volumes and strengths than municipal wastewater, due to increased waste production relative to management practices, involving ad libitum swine production feeding, reduced dilution rates when compared to human sewage, and liquid waste concentration in pits and/or lagoons. The decentralized nature of most swine waste production facilities relative to human sewage treatment facilities and increased energy and labor-intensive waste treatment techniques compared to human wastewater treatment may result in higher treatment costs relative to benefits received.

OBJECTIVE

This project consisted of three studies designed to evaluate the practicality of mechanical solids separation of swine slurry as a best management practice for handling liquid swine manure. Study One evaluated the efficiency of a polyacrylimide (PAM)-aided swine waste slurry solids separation treatment to reduce commonly used aquatic pollution indicators in the treated product. Treatments evaluated were solids separation through gravity settling (sedimentation) before and after the addition of four different concentrations of proprietary polymeric (PAM) flocculant. The goal of this study was to determine both the practical and economic feasibility of use of polymer-aided solids separation to reduce swine waste pollution indicators to acceptable levels for further treatment or discharge into the environment without resulting environmental degradation. Study Two evaluated the efficiency of a static gravity screen-roll press combination solids separator system and a polyacrylamide (PAM)-assisted gravity belt solids thickener system, alone and in conjunction, to reduce the concentration of solids and other commonly used aquatic pollution indicators in the treated product relative to raw unprocessed swine waste slurry. Treatments applied were 1) solid/liquid separation of raw unprocessed slurry (RS) by using a static gravity screen-roll press combination separator system to produce a separated effluent (SE), 2) RS treatment by a PAM-assisted gravity belt thickener system to produce a separated effluent (BE1), and 3) additional SE treatment by a PAM-assisted gravity belt thickener system to produce a separated effluent (BE2). A comparison of the data generated was then used to determine the feasibility of using these treatment systems alone or in combination to reduce

swine waste pollution indicators prior to additional treatment or discharge into the environment. Study Three evaluated the effectiveness of polyacrylamide (chemical flocculant) – assisted separation for reducing odor in separated effluent.

PROCEDURES

Study One:

Swine Waste Slurry Types Collected And Corresponding Polymer Amendment Concentrations

Gestation, farrowing, nursery and grow/finish swine waste slurry type samples were collected and tested for settleable solids (SS), total suspended solids (TSS), dissolved oxygen (DO), chemical oxygen demand (COD), phosphorus (P) and nitrogen (N) concentrations, and pH prior to and following amendment with four concentrations of a proprietary cationic polyacrylamide (PAM) polymer flocculant (Percol ® 757, Ciba Specialty Chemical Water Treatments, Inc.; Suffolk, VA). The PAM charge density was 58%, the intrinsic viscosity was 6-8 units, and the percentage active solids was >99.9%. The slurry types chosen for analysis represented waste generated during a range of swine production development stages. All four slurry types were amended with PAM concentration of 0.075% and 0.0375%, or 750 and 375 mg/l, while additional samples of grow/finish slurry were separately amended with PAM concentrations or 0.00625% and 0.0125%, or 125 and 62.5 mg/l. Polyacrylamide concentrations tested were initially based upon manufacturer's recommendations, then reduced by 50% in subsequently tested samples until lowest optimal PAM concentrations of 62.5 mg/l were identified. Therefore, additional samples tested were amended only with the two lowest effective PAM concentrations. Since separation efficiencies were similar among the four slurry types evaluated using the higher PAM concentrations, the two lower PAM concentrations (125 and 62.5 mg/l) were evaluated using only grow-finish slurry. COD was chosen to measure organic load rather than BOD due to the potential for antibiotics transferred to swine waste to affect BOD results. Four pits of grow/finish, farrowing, nursery, and gestation slurry were sampled and analyzed twelve times each (n = 12) for a total number of 48 analyses (N = 48). Two pits of grow/finish slurry at 125 and 62.5 mg/l PAM concentration were also sampled and analyzed twelve times each (n=12) for a total number of 24 analyses (N=24).

Analyses Performed

Jar-test protocols used to evaluate solids-separation efficiency were adapted from Sanks (1978), Hach Company® (1992) and Hammer and Hammer (2001). Swine waste slurry sub-samples of 500 ml were dispensed into 1000 ml glass beakers and appropriate amounts of PAM added to reach the final desired concentration. Mixing was accomplished by use of a Hach® six-paddle, adjustable-speed jar-test apparatus (Hach Company®; Loveland, CO). Mixing was initiated at approximately 30-revolutions per minute (rpm) and maintained for 10 min to accomplish thorough mixing and to allow particle coagulation and flocculant (floc) formation (flocculation). Slurry samples were then transferred to 1.0 liter settleometers (Imhoff cones) for measurement of settleable solids (SS) according to Standard Methods for the Examination of Water and Wastewater, 20th ed. (2000). Samples were allowed to stand for 45-min, settleometers rotated to dislodge floc solids clinging to the sides of the funnel, and floc solids allowed to settle for an

additional 15 min. Non-PAM amended (raw) swine slurry samples were concurrently analyzed for SS using the same techniques. Results were then read, calculated, recorded and reported in units of ml/l SS. Slurry pH values were determined using a Corning® pH meter model 7 (Corning Inc., Corning, NY) recorded and reported in 0-14 standard pH scale unites. Adjustment of pH was not considered to be necessary for optimal PAM flocculation efficiency by the manufacturer.

Total suspended solids concentrations were determined for both raw and PAM-amended swine slurry using Standard Methods for the Examination of Water and Wastewater, 20th ed. (2000). Measured liquid samples of settled slurry were passed through pre-weighed glass fiber filters using a funnel filtration apparatus subjected to a partial-vacuum. Filters were heated to dryness and final weight determined. Total suspended solids concentrations were calculated based on the difference in weight prior to and following drying and results recorded and reported in mg/l TSS. Slurry solids dry weight was determined by heating samples to dryness and calculating solids dry weight basis in mg/l by comparing initial to final weights.

Dissolved oxygen levels were measured using either a direct-reading Corning Multimeter® (Corning Inc., Corning NY) or Hanna (Hanna Instruments, Portugal) DO Meter. COD was determined using a Hach® (Hach Company®, Loveland, CO) Micro-Digestion procedure. This procedure involved the addition of a measured amount of an appropriately diluted sample to a digestion vial containing chromic and sulfuric acids and colorimic indicator reagents. The sample digested by heating in a COD reactor dry block heater (Hach® Co., Loveland, CO) in the presence of acids at 150 °C for 90 min. The sample was then prepared and analyzed colorimetrically using a Hach® model 2000 spectrophotometer. Samples of both raw and polymer-amended slurry were analyzed for COD. Results were calculated, recorded and reported in g/l COD.

Nitrogen concentrations were determined as total nitrogen by the micro-Kjeldhl method. Phosphorus concentrations were determined by methods as described by the Association of Analytical Chemists (AOAC, 1975). Slurry nitrogen and phosphorus concentrations were recorded and reported in mg/l.

STATISTICAL ANALYSES

Statistical analysis of SS, TSS, COD, P and N concentrations (dependent variables) were conducted for PAM concentrations of 750,375, 125, and 62.5 mg/l (independent variables) using a protected *F*-test (using SPSS® software).

Study Two:

Swine Waste Slurry Types Collected, Corresponding Treatments, and PAM Addition Concentrations

Raw unprocessed gestation, farrowing, nursery, and grow-finish swine waste slurry were co-mingled in an 2.24-m deep holding pit. Prior to sampling, slurry was agitated to re-suspend settled solids. Raw slurry (RS) samples were collected using a 2.40-m probe and separated into

solid and liquid fractions using a static gravity screen-roll press combination system, with the screen effluent designated SE. The screen-roll press separator used during this study was a Model 100, manufactured by Key Dollar Cab, Inc. (114 Southwest 5th St., Milton-Freewater, OR 97862). The screen pore size was 0.16-cm, and its maximum capacity was 378.8 liters per minute (lpm) or 100 gallons:minute (g:m). For purposed of this study, it was operated at a rate of 227.1 ± 1.02-lpm, or 60g:m. Raw slurry was also treated using a polyacrylamide (PAM)-assisted gravity belt thickener system, with the first belt effluent designated BE1. The belt thickener system used was Model GSC-1, Series III manufactured by Komline-Sanderson (12 Holland Ave., Box 257, Peapack, NJ 07977). The belt fabric permeability was 390 lpm, and the maximum capacity of this system was 567.8-lpm (150g:m). For purposes of this study, it was operated at a rate of 103.7 ± 1.63-lpm (27.4g:m). Additionally, SE was treated using the same PAM-assisted gravity belt thickener system, with the second belt effluent designated BE2. Duplicate 500-ml sub-samples of RS, SE, BE1 and BE2 were collected for analysis. Sub-samples were then analyzed for settleable solids (SS), total suspended solids (TSS), solids dry weight (SDW), pH, DO, COD, P and N concentrations. Chemical oxygen demand was chosen to indicate organic load rather than biochemical oxygen demand (BOD) due to the potential for antibiotics to be transferred to swine waste and affect BOD results. The proprietary cationic polyacrylamide (PAM) polymer flocculant used was Percol 757® (Ciba Specialty Chemical Water Treatments, Inc.; Suffolk, VA). Percol 757® charge density was 58%, the intrinsic viscosity was 6-8 units, and the percentage active solids were. 99.9%. Raw slurry was amended with a Percol 757® concentration of 0.014%, or 140 milligrams per liter (mg/l). Percol 757® concentrations chosen were based on previously-determined optimal concentrations for swine waste slurry [24]. Approximately 3,312-l (875g) of RS were collected, separated and analyzed on eight occasions for a total volume of approximately 26,496-l (7000g) treated. Samples were separated on-site under typical field conditions at the Illinois State University (ISU) Farm – Normal.

Analyses Performed

Raw slurry and effluent pH values were determined using a Corning® pH meter model 7 (Corning Inc.; Corning, NY) recorded and reported in standard 0-14 pH scale units. Raw slurry and treated effluent samples were transferred to 1.0-l settleometers (Imhoff cones) for SS determination according to Standard Methods for the Examination of Water and Wastewater, 20 Ed. (Eaton, 2000). Samples were diluted with 500-ml deionized water and allowed to stand for 45-minutes, settleometers rotated to dislodge solids clinging to the sides of the funnel, and solids allowed to settle for 15 additional minutes, for a total settling time of 1-h. Results were read, calculated, recorded and reported in units of ml/L SS. Slurry and effluent SDW was determined by heating samples to dryness and calculating solids dry weight basis in mg/L by comparing initial to final weights. Total suspended concentrations were determined by slurry effluents using Standard Methods for the Examination of Water and Wastewater, 20 Ed. (Eaton, 2000). Measured liquid samples of effluent were passed through pre-weighed glass filters using a funnel filtration apparatus subjected to a partial vacuum. Filters were heated to dryness and final weight determined. Total suspended solids concentrations were calculated based on the difference in weight prior to and following drying and results recorded in mg/L TSS. Dissolved oxygen levels were measured using a Hanna (Hanna Instruments, Portugal) DO Meter. COD was determined using a Hach® (Hach Company®; Loveland, OC) Micro-Digestion Procedure. This procedure

involved the addition of a measured amount of an appropriately diluted sample to a digestion vial containing chromic and sulfuric acids and colorimetric indicator reagents. The sample was digested by heating in a dry block heater (Hach® COD reactor) in the presence of acids at 150-degrees C for 90-minutes. The sample was then prepared and analyzed colorimetrically using a Hach® model 2000 spectrophotometer. Samples of RS and effluents were analyzed for COD. Results were calculated and recorded in g/L COD.
N concentrations were determined as total nitrogen by the micro-Kjeldahl method. Phosphorus concentrations were determined by methods as described by the Association of Analytical Chemists (AOAC) (1975). Raw slurry and effluent N and P concentrations were recorded in mg/L.

Statistical analyses methods
Statistical analysis of SS, TSS, COD, P and N concentrations (dependent variable) were conducted for RS, SE, BE1 and BE2 (independent variables) using a protected F-test (SPSS® software, 1998).

Study Three:

Gestation/Lactation And Grow/Finish

Swine slurry samples were collected and analyzed for selected volatile organic compounds prior to and following amendment with two concentrations of a proprietary cationic polyacrylamide (PAM) polymer flocculent (Percol® 757, Ciba Specialty chemical Water Treatments, Inc.; Suffolk, VA). The PAM charge density was 58%, the intrinsic viscosity was 6-8 units, and the the percentage active solids was >99.9%. Raw slurry samples were collected from a 2.24 m (88 inches) deep holding pit using a 2.4 m (94.5 inches) probe. Prior to sampling, slurry was agitated to re-suspend settled solids. Twenty four samples of each slurry type were collected and 12 samples of each type of raw slurry were amended with 0.075% or 750 mg/l of PAM. The remaining 12 samples of each slurry type were placed into glass jars with Teflon caps and refrigerated at 4°C until analysis.

Analyses Performed

Jar-test protocols used to evaluate solids-separation efficiency were adapted from Sanks (1978), Hach Company® (1992) and Hammer and Hammer (2001). In a ventilated room and under a chemical hood swine slurry sub-samples of 500 ml were dispensed into 1000 ml glass beakers and appropriate amounts of PAM added to reach the desired final concentration. Mixing was accomplished by use of a Hach® six-paddle, adjustable-speed jar-test apparatus (Hach Company®; Loveland, CO). Mixing was initiated at approximately 30-revolutions per minute (rpm) and maintained for 10 min to accomplish thorough mixing and to allow particle coagulation and flocculant (floc) formation (flocculation). Slurry samples were then transferred to 1.0 liter settleometers (Imhoff cones) for measurement of settleable solids (SS) according to Standard Methods for the Examination of Water and Wastewater, 20th ed. (2000). Samples were allowed to stand for 45-min, settleometers rotated to dislodge floc solids clinging to the sides of the funnel, and floc solids allowed to settle for an additional 15 min. Subsequent to settling, the

effluent was siphoned off, placed into glass jars with Teflon caps and refrigerated at 4°C until analysis.

A two gram sample from each of the 24 raw slurry samples and 24 effluent samples plus 5 ml of a matrix modifier solution (deodorized 2 M aqueous citrate-phosphate buffer, pH 5, saturated with NaCl) and 5µL of internal standard solution (1.19 mg/mL of *tert*-amylphenol, 1.13 mg/mL of 2-methylindole and 13.4 mg/mL of 2-ethylbutanoic acid in methanol) was transferred to a 22-mL glass headspace vial and the vial was sealed with a Teflon-faced silicon septum.. Duplicate vials were prepared from each sample.

Analysis system consisted of an Agilent 6890 GC (Agilent Technologies, Inc., Palo Alto, CA) equipped with a flame ionization detector (FID) and MPS2 (SPME mode) autosampler (Gerstel, Germany). For SPME, vial was preincubated at 60°C for 10 min with agitation (500 rpm, 5 s on, 2 s off). Then a SPME fiber (Carboxen/polydimethylsiloxane fiber, Supelco, Bellefonte, PA) was exposed to the vial headspace for an additional 20 min. Immediately after sampling, the fiber was destrobed by spitless injection (injector temperature 260°C, spitless time 4 min; split vent flow 50mL/min) into a Stabilwax® DA GC column (15 m x 0.32 mm i.d. x 0.5 µm film; Restek, Bellefonte, PA). GC oven temperature was programmed from 35 to 225°C at a rate of 10°C/min with initial and final hold times of 5 and 10 min respectively. For qualitative analysis an Agilent 5973 mass selective detector (MSD; Agilent Technologies, Inc.) was used as the GC detector.

Compounds were identified by comparison of their mass spectra and retention indices (Van den Dool and Kratz, 1963) with those of reference standards.

GC-FID response factor (f_i) for each compound was determined by addition of known amounts of reference standards into 5-mL of matrix modifier solution containing 2mL of deodorized water prior to analysis. Sample preparation and GC-FID analysis were performed in the same way as described above for samples, with the assumption that the extraction rates of individual volatile compounds in this matrix were similar to those in the sample matrix. FID response factors (f_i) were used to calculate actual concentrations according to Zhou et al. (2002). Internal standard *tert*-amylphenol was used to determine f_i values for phenol, 4-methylphenol and 4-ethylphenol, while internal standard 2-methylindole was used for indole and 3-methylindole, and internal standard 2-ethylbutanoic acid was used for acetic, propanoic, isobutryic, butyric, 3-methylbutyric, pentanoic, hexanoic, phenylacetic and 3-phenylacetic acids.

STATISTICAL ANALYSIS METHODS

Data generated were subjected to paired t-test analysis to compare volatile organic compound concentrations in raw slurry and separated effluent for each of the two slurry types. Significance level was set at $P < 0.05$.

RESULTS

Study One:

Data presented in Table 1 indicate that SS recovered from all PAM-amended slurry types analyzed increased from 10% to 34%, with a mean increase of 20% for a 750 mg/l PAM concentration. Settleable solids increases were greater for grow/finish slurry tested separately at PAM concentrations of 125 and 62.5 mg/l (Table 2) with a range of solids recovery increase from 43%-49%.

Total suspended solids concentration reductions ranged from 77% to 99% with mean TSS concentration reductions of 92-93% for 750 and 375 mg/l PAM concentrations. TSS concentration reductions were >99% in growth/finish slurry analyzed again alone at both PAM concentration levels tested. These data support the assumption that TSS were converted to SS through coagulation and flocculation following slurry PAM amendment and mixing.

Raw slurry moisture content in this study ranged from approximately 98% to 93% (2-7% solids dry weight). Added PAM weights ranged from 10.85 to 0.91 kg/dry tonne, corresponding to 750-62.5mg/l. respectively. Observed slurry pH levels ranged from 6.8 for raw grow/finish slurry to 7.6 for PAM-amended gestation slurry, with a mean of 7.2-7.3 for samples amended with 750 and 375 mg/l PAM concentrations.

Data presented in Tables 3 and 4 indicate that COD concentration reductions in PAM-amended slurry ranged widely from below zero (an increase of 2-19%) to 52%, with calculated mean concentration reductions of 15-27% for samples amended with 750 and 375 mg/l PAM concentrations. DO concentrations were below the minimum detection limit (MDL) of 0.01 mg/l for all slurry samples analyzed. Phosphorus concentration reductions were slightly more consistent than those of COD, ranging from 10-99%, with calculated means of 63-80% for samples amended with 750 and 375 mg/l PAM concentrations. N concentration reductions were the most consistent of the data presented in Tables 3 and 4, ranging from 48% to 86%, with corresponding means of 68-77% for samples amended with 750 and 375 mg/l PAM concentrations. Data concerning nutrient composition of the diets fed the swine generating the slurry during the time frame of this study are presented in Tables 5 and 6 and represent analyzed values.

Study Two:

Results of RS and effluent SS, TSS, pH, SDW, COD, P and N and related concentration reduction efficiencies are presented in Tables 7 and 8. Table 8 contains data concerning COD, P, and N concentrations and related treatment efficiencies.

Data presented in Table 7 indicate that SS concentrations recovered were significantly ($p \leq 0.05$) reduced to below the MDL of 0.1 ml/L in BE1 and BE2 by > 99%, relative to RS. A substantial, although non-significant ($p > 0.05$) 59.1% concentration was found for SE relative to RS. Suspended solids (TSS) concentration reductions were also significant for BE1 (94.7%) and BE2 (93.9%) relative to RS. A 9.1% TSS concentration reduction in SE relative to RS was son-

significant. Solids dry weight concentration reductions (27-96%) were significant for all three effluent types (SE, BE1 and BE2), relative to RS. Consistent pH levels were found among RS and the three effluents generated in the range of 7.6-7.7.

Data presented in Table 2 indicate that COD concentration reductions of 18.2% for SE relative to RS were non-significant, while significant concentration reductions were generated for BE1 (84.7%) and BE2 (63%). Dissolved oxygen concentrations were below the MDL of 0.01 mg/L for RS and SE, and at 0.5 mg/L for BE1 and BE2. Phosphorus concentration reductions of 20.3% were non-significant for SE, but were significant for BE1 (79.5%) and BE2 (70.8%), relative to RS.

Data were analyzed using SPSS® protected F-test statistical analyses (Tables 7-8). Significant concentration reductions were consistently generated for SS, TSS, SDW, COD, P, and N in BE1 and BE2 relative to RS, using the PAM assisted gravity belt thickener system. Significant concentration reductions were generated for SDW and P only using the static gravity screen-roll press system. No significant differences were found between BE1 and BE2 effluents.

Study Three:

Three of the 17 volatile organic compounds (VOC) selected for analysis were below the minimum detection limits (Table 10) in each of the two raw slurry types and resulting separated effluents. Of the remaining 14 VOC, the concentration of each VOC was reduced ($p < 0.05$) in the effluent separated from the gestation/lactation slurry compared to the raw slurry and 12 of the VOC were significantly reduced in the effluent separated from the grow/finish slurry compared to the raw slurry. The percent range in VOC ranged from 20 to 99 with five having a percent change of 82 to 99. Phenylacetic acid and 3-phenylpropanoic acid concentrations were significantly reduced in gestation/lactation effluent but not in the grow/finish effluent.

DISCUSSION

Results generated by these studies support research findings that optimal swine waste slurry PAM-amendment concentrations between 10 and 500 mg/l were optimal for solids separation. Ndegwa et al. (2001) found that swine slurry solids concentrations from 1% to 2% (dry weight) were optimal for "natural" (gravity) sedimentation, but slurry with solids concentrations in the 5-7% range require additional treatment for effective separation. Phosphorus reductions of 42-86% and 78% were found by Ndegwa et al. (2001) for slurry amended with 1500 mg/l ferric chloride and aluminum sulfate which is similar to the 63-80% concentration reductions generated during this study for PAM. Vanotti and Hunt (1996), evaluating the use of PAM flocculants to remove solids form dilute waste waters, found that application of 10 mg/l PAM reduced suspended solids (SS), chemical oxygen demand (COD), and organic nitrogen by 33%, 38% and 82% respectively. Vanotti and Hunt (1999) found that PAM concentrations of 26-79 mg/l reduced initial TSS concentrations of 1.5-4.1 g/l by 90-94%. Sievers et al. (1994), testing two supernatants generated from (1) settled slurry and (2) anaerobic digestion that contained 0.1%-1.0% total solids, found that polymers proved to be "excellent" coagulants for swine waste treatment (yielding approximately 20-30% volatile solids concentration reductions at 3-4 mg/l polymer concentrations). Sievers et al. (1994) concluded that synthetic polymers were the most

cost-effective chemical coagulant for dilute swine wastewater and observed that polymers were nontoxic, which should limit potential concerns for the reutilization of solids as feed additives, compost or as a soil amendment. Sievers et al. (1994) also observed that polymers were biodegradable and therefore may avoid concerns for potential accumulation of metal ions in solids from use of metallic salt chemical coagulants such as ferric chloride and aluminum sulfate.

For an odor-active compound such as that found in raw slurry or separated effluent, its concentration can be converted to an odor-activity value (OAV; ratio of the concentration of an odorant to its detection threshold) in order to gauge the compound's potential contribution to the overall perceived odor of the sample. An OAV over unity (1) would mean that a compound is present at above its threshold and should, therefore, make some contribution odor. However, the OAV concept gives, at best, only a rough estimate of odor intensity (Audouin et al. 2001). As example, for 4-methyphenol (Table 11) there is a reduction from ~ 750 to ~ 20 mg/L, corresponding to OAVs of 270,000 and 7400, respectively. This represents a large numerical reduction but 4-methylphenol probably still will be perceivable and contribute to odor. Only one VOC, penol, was found to have a calculated OAV below one in the separated effluent even though separation significantly decreased the VOC concentrations. This suggests that while the separated effluent may have a less offensive odor than raw slurry it probably still has a detective odor.

Polymer-assisted gravity belt thickener treatment was more effective at achieving solids separation from raw unprocessed swine waste slurry (RS) than the static gravity screen-roll press treatment tested. Screening and belt solids separation efficiencies found in this study appear to be roughly comparable to those found in previous studies (Glenrum et al., 1971, Graves and Clayton, 1972, Shutt et al., 1975, Shirley and Butchbaker, 1975, Rorick et al., 1980, Prince and Hill, 1985, Fernandes et al., 1988, Koegel et al., 1990, Severin and Grethlein, 1996, hill and Baier, 2000). It also was observed during this study that more frequent adjustment of PAM concentrations was required to maintain consistent solids separation when RS was separated to generate BE1, compared to when SE was separated to produce BE2.

Results indicated that application of PAM-assisted belt thickening treatment directly to RS was more efficient than application to pre-treated SE for concentration reduction of TSS, COD, P, and N parameters. Therefore, results suggest that a PAM-assisted belt thickening system can be adapted from traditional human sewage biosolids dewatering use and applied directly on-site to RS without the necessity of an intermediate treatment to reduce solids. It should be noted that higher PAM levels (140 mg/L) are required for treatment of swine waste solids relative to human sewage biosolids, which have a typical added polymer range of 1-10 mg/L. This added polymer cost may be offset by the lack of necessary pretreatment prior to solids belt thickening. The N:P ratios generated from this study were significantly greater for BE1 and BE2 compared to RS. No significant differences ($p<0.05$) were found between RS and SE. The N:P ratios of BE1 and BE2 more closely approximate the sufficiency range of these two nutrients in the whole corn plant (Voss, 1993), suggesting that BE1 and BE2 are more suitable for land application as a soil amendment for corn production than RS or SE.

Table 9 indicates the calculated costs for operating the two types of separators compared during the study. While the gravity screen-roll press separator was not as effective as the PAM assisted

gravity belt thickener, the calculated cost to operate the gravity screen unit was minimal. Therefore, combining the two systems in tandem to separate raw slurry may be an economically feasible approach. An observed advantage for using the two systems in tandem was less frequent adjustment in polymer concentration was required when PAM was added to SE compared to RS. Apparently the gravity screen system removed sufficient SS to produce a SE with a more consistent SDW; as the amount of PAM required is proportionate to SDW concentration.

Current soil application methods for swine slurry include broadcast spreading followed by incorporation, direct soil injection, and sprinkler irrigation. Of these three methods the most common method is direct soil injection, generally utilizing a slurry tank and injection knives. This system costs approximately 0.198¢ per liter (0.8¢:gal) of slurry (Merna, 2000). Center pivot irrigation is the least costly method, costing approximately 0.026¢ per liter (0.1¢:gal) of slurry but results in the greatest potential for odor pollution and is consequently used less frequently (based on calculations assuming 2 million gal:yr swine slurry, 1000g:min application rate, 34 hours of operation at an electricity rate of $1.50:hr, irrigator purchase cost of $40,000 for 75 acre unit and a 20 yr. operational lifespan). Both injection and irrigation can result in excess nitrogen and phosphorus land application rates. Composting offers an acceptable swine waste management alternative but is impractical for many larger scale swine confinement operations due to the high amount of carbon (corn stalks, leaves, woodchips, etc.) required to compliment the moisture and nitrogen content of slurry (Walker et al., 2000). Coupling solid-liquid separation with composting of solids and irrigation of the liquid component of slurry may be an acceptable disposal strategy if the cost of separation can be limited to approximately 0.185-0.225¢ per liter (0.75 -0.9¢:gal.) of raw slurry. Estimated costs associated with the levels of PAM used in this study ranged from 0.053¢ per liter (at 62.5 mg/l) to 0.679¢ per liter (at 750 mg/l) (0.22 – 2.72¢:gal) when the PAM cost was $4.51 per kilogram ($9.90:lb). The lower efficient PAM amendment rates used in this study 62.5 and 125 mg/l suggest a slurry application system that combines separation and irrigation could compare favorably with other methods of slurry disposal such as soil injection. In order for producers to incorporate PAM separation into their slurry application process, the combined cost of PAM-assisted separation and land application must be comparable to the cost of the slurry tank-dragline system described previously. Therefore, PAM separation must be combined with an irrigation system and the raw slurry flow rate increased by at least 83.5% to 190.4 lpm (50.3 gpm). This might be accomplished by selecting a different PAM than used in this study or varying the tested PAM concentration rate. Additional research in this area is needed.

CONCLUSIONS

Results generated by this study support the previous research consensus that solids separation from swine waste slurry is enhanced by use of a proprietary chemical polymer (PAM) flocculation treatment. Most importantly, phosphorous concentration in separated effluent is consistently reduced 80-90%, nitrogen concentration is reduced 50-70% and the nitrogen:phosphorous ratio is improved to approximately 15:1 making separated effluent more preferable as a soil amendment than raw slurry.

Slurry DO concentrations below the MDL of 0.1 mg/l in all sample types and COD levels exceeding from 4 to 38 g/l following solids separation indicate remaining concern for oxygen

depletion of separated effluent. Concentrations of volatile organic compounds contributing to odor were reduced by PAM separation but odor activity values suggest that while separated effluent may have less objectionable odor than raw slurry, sufficient volatile organic compounds remain in separated effluent to produce odor. Therefore, further treatment of the effluent generated from slurry solids separation prior to discharge into the environment is advisable. However, results suggested that PAM-aided solids separation facilitates further effluent treatment and may therefore reduce the potential for environmental degradation following solids reutilization, land application, or disposal. Mechanical separation without PAM assistance was found to change raw slurry very little but does have potential when coupled with PAM-assisted separation to improve separation efficiency. Combining PAM assisted separation with irrigation may be similar in cost to soil injection as a method for land application of swine slurry.

ACKNOWLEDGEMENTS

This study was partially funded by grants from Illinois Council for Food and Agricultural Research (C-FAR) and the Illinois Department of Agriculture Sustainable Agriculture Grants Program. Their continuing support for this research is greatly appreciated.

SOLID/LIQUID SEPARATION AND SWINE SLURRY BULLET POINTS

1. Mechanical separation without polymer assistance:
   a. Typically removes 30-40% of settleable solids.
   b. Has little effect on suspended solids, nitrogen or phosphorus concentrations.
   c. Is a low-cost separation procedure (.29¢: 1000 gallons).
   d. Increases odor emission during separation.

2. Polymer assisted mechanical separation:
   e. Consistently removes 80-90% of the phosphorous concentration.
   f. Consistently removes 50-70% of the nitrogen concentration.
   g. Reduces the settleable solids concentration up to 99%,
   h. Reduces suspended solids concentration up to 95%.
   i. Improves the N:P ratio from 4:1 up to 25:1, generally averaging around 15:1.
   j. Has some effect of reducing the odor of the separated effluent.
   k. Must be operated in a closed building equipped with a biological filter to control odor emissions during separation.
   l. Can be cost effective for operations producing 2 million gallons or more of slurry per year.
   m. Must be combined with irrigation to be cost competitive to typical injection systems.
   n. Works well in conjunction with composting if solids are composted and effluent is irrigated.

3. Separations greatest value is in:
   a. Reducing the cost of land applying the separated effluent.
   b. Facilitating composting of the solids for off-farm removal.
   c. Reducing the volume of manure that must be hauled off farm due to high phosphorous concentrations.

Table 1. Swine waste slurry solids concentration reduction treatment efficiency with PAM addition at 750 and 375 mg/L concentrations (for all four slurry types) and associated solids dry weight ($\mu \pm 1SE$), PAM concentration and pH values.

Swine waste slurry type (n = 12, N = 48, 24)	**Settleable Solids (SS) (ml/L)**	**SS Recovery Increase (%)**	**Suspended Solids (TSS) (mg/L)**	**TSS Conc. Reduction (%)**	**Solids Dry Weight (%)**	**PAM Conc. (kg/dry Tonne)**	**pH**
Gestation (2 pits)							
Raw slurry	211 ± 34		162.5 ± 0.1		5.70 ± 0.22		7.5 ± 0.01
+ PAM (750 mg/l conc.)	248 ± 11	14.92	35 ± 0.1[a]	78.46		10.85	7.6 ± 0.03
+ PAM (375 mg/l conc.)	254 ± 13	16.93	38 ± 0.1[b]	76.62		5.43	7.6 ± 0.01
Farrowing (4 pits)							
Raw slurry	130 ± 12		67.5 ± 0.1		5.70 ± 0.02		7.3 ± 0.01
+ PAM (750 mg/l conc.)	182 ± 9[a]	28.57	1.4 ± 0.1[a]	97.93		10.85	7.4 ± 0.02
+ PAM (375 mg/l conc.)	198 ± 8[a]	34.34	3.4 ± 0.1[b]	94.96		5.43	7.4 ± 0.02
Nursery (4 pits)							
Raw slurry	294 ± 11[ab]		140.8 ± 0.1		7.30 ± 2.82		7.1 ± 0.03
+ PAM (750 mg/l conc.)	327 ± 7[a]	10.09	4.4 ± 0.1[a]	96.88		8.48	7.3 ± 0.03
+ PAM (375 mg/l conc.)	367 ± 12[b]	19.89	6.5 ± 0.1[b]	95.38		4.24	7.1 ± 0.01
Grow/finish (4 pits)							
Raw slurry	263 ± 24		177.3 ± 15.3		5.68 ± 0.28		6.8 ± 0.02
+ PAM (750 mg/l conc.)	350 ± 16[a]	24.86	14.7 ± 2.3[a]	99.17		10.90	6.9 ± 0.02
+ PAM (375 mg/l conc.)	364 ± 12[a]	27.77	7.8 ± 2.5[b]	99.56		5.45	6.9 ± 0.02
All four slurry types							
Raw slurry	224.50±13.55		536 ± 56.09				7.2 ± 0.05
+ PAM (750 mg/l conc.)	276.75 ± 4.19[a]	19.61 ± 3.71	18.50 ± .83[a]	93.11 ± 4.25			7.3 ± 0.02
+ PAM (375 mg/l conc.)	295.75 ± 4.57[b]	24.73 ± 3.41	13.93 ± 0.88[a]	91.63 ± 4.43			7.3 ± 0.02

[a,b] Significant difference (within columns) at $p < 0.05$ level.

Table 2. Swine waste slurry solids concentration reduction treatment efficiency with PAM addition at 125 and 62.5 mg/l concentrations (grow/finish slurry only) and associated solids dry weight (μ ± 1 SE), PAM concentration and pH values.

Swine waste slurry type (n = 12, N = 24)	**Settleable Solids (SS) (ml/l)**	**SS Recovery Increase (%)**	**Suspended Solids (TSS) (mg/l)**	**TSS Conc. Reduction (%)**	**Solids Dry Weight (%)**	**PAM Conc. (Kg/dry tonne)**	**pH**
Grow/finish (2 pits)							
Raw slurry	69 ± 7.0		65 ± 0.1		2.17 ± 0.34		6.8 ± 0.3
+ PAM (125 mg/l conc.)	136 ± 5.0[a]	49.26	<0.01[a]	>99.98		1.82	7.0 ± 0.2
+ PAM (62.5 mg/l conc.)	120 ± 4.5[a]	42.50	<0.01[a]	>99.98		0.91	6.9 ± 0.2

[a,b] Significant difference (within columns) at $p<0.05$ level.

Table 3. Swine waste slurry treatment COD, P, and N concentration reduction efficiency with PAM addition at 750 and 375 mg/l concentrations (μ ± 1 SE for all four slurry types).

Swine Waste Slurry Type (n = 12, N = 48, 24)	**Chemical O_2 demand (COD) (g/l)**	**COD Conc. Reduction (%)**	**Phosphorous (P) (mg/l)**	**P Conc. Reduction (%)**	**Nitrogen (N) (mg/l)**	**N Conc. Reduction (%)**
Gestation (2 pits)						
Raw slurry	12.88 ± 3.29		10.0 ± 0.02		60 ± 0.07	
+ PAM (750 mg/l conc.)	13.16 ± 2.81	0 (+2.17)	1.0 ± 0.04[a]	90.00	20 ± 0.02[a]	66.67
+ PAM (375 mg/l conc.)	11.55 ± 1.76	10.33	1.0 ± 0.03[a]	90.00	15 ± 0.01[a]	75.00
Farrowing (4 pits)						
Raw slurry	6.79 ± 1.31		1.6 ± 0.01		30 ± 0.01	
+ PAM (750 mg/l conc.)	3.94 ± 0.60	41.97	0.2 ± 0.01[a]	87.50	10 ± 0.01[a]	66.67
+ PAM (375 mg/l conc.)	6.25 ± 1.26	7.95	0.6 ± 0.01[b]	62.50	10 ± 0.01[a]	66.67
Nursery (4 pits)						
Raw slurry	15.62 ± 1.72[ab]		8.0 ± 0.02		56 ± 0.09	
+ PAM (750 mg/l conc.)	11.82 ± 1.17[a]	24.33	0.7 ± 0.01[a]	91.25	15 ± 0.02[a]	73.21
+ PAM (375 mg/l conc.)	18.64 ± 2.71[b]	0 (+19.33)	1.0 ± 0.03[a]	87.50	8 ± 0.01[a]	85.71
Grow/finish (4 pits)						
Raw slurry	42.04 ± 13.70		1.0 ± 0.01		52 ± 0.01	
+ PAM (750 mg/l conc.)	24.94 ± 3.80[a]	40.68	0.5 ± 0.01[a]	50.00	17 ± 0.07[a]	67.31
+ PAM (375 mg/l conc.)	25.03 ± 3.83[a]	42.84	0.9 ± 0.01	10.00	10 ± 0.06[a]	80.77
All four slurry types						
Raw slurry	19.33 ± 2.95		5.20 ± 4.50		50 ± 3.25	
+ PAM (750 mg/l conc.)	13.46 ± 0.47[a]	26.75 ± 8.47	0.60 ± 0.02[a]	79.69 ± 8.60	15.5 ± 0.23[a]	68.47 ± 1.38
+ PAM (375 mg/l conc.)	15.34 ± 0.45[a]	15.28 ± 8.19	0.88 ± 0.01[a]	62.50 ± 16.08	11.0 ± 0.16[b]	77.04 ± 3.54

[a,b] Significant difference (within columns) $p< 0.05$ level.

Table 4. Swine waste slurry treatment COD, P, and N concentration reduction efficiency with PAM addition at 125 and 62.5 mg/l concentrations (μ ± 1 SE for grow/finish slurry only).

Swine waste slurry type (n = 12, N = 24)	**Chemical O_2 demand (COD) (g/l)**	**COD Conc. Reduction (%)**	**Phosphorous (P) (mg/l)**	**P Conc. Reduction (%)**	**Nitrogen (N) (mg/l)**	**N Conc. Reduction (%)**
Grow/finish (2 pits)						
Raw slurry	37.48 ± 10.47		41 ± 0.92		21 ± 0.12	
+ PAM (125 mg/l conc.)	38.13 ± 0.98	0 (+1.73)	<0.01[a]	>99.97	11 ± 0.01[a]	47.62
+ PAM (62.5 mg/l conc.)	17.70 ± 1.15[a]	52.77	20 ± 0.04[b]	95.13	9 ± 0.01[a]	57.14

[a,b] Significant difference (within columns) at $p<.05$ level.

Table 5. Nutrient concentrations of swine diets fed during the time frame of this study (%, μ ± 1 SD).

Diet/Slurry type (N=12)	**Wet Ash**	**Phosphorus**	**Nitrogen**	**Crude Protein**	**ADF**	**Ether Extract**
Gestation	6.83 ± 0.67	0.11 ± 0.00	1.67 ± 0.04	10.44 ± 0.27	5.05 ± 0.13	2.80 ± 0.02
Farrowing	6.79 ± 4.01	0.07 ± 0.05	2.36 ± 1.58	14.72 ± 9.89	4.83 ± 3.43	7.00 ± 5.00
Nursery	7.16 ± 0.44	0.08 ± 0.00	3.76 ± 0.14	23.50 ± 0.88	4.79 ± 0.27	5.52 ± 0.06
Grow/Finish	4.83 ± 0.23	0.07 ± 0.00	3.44 ± 0.15	21.50 ± 0.93	4.74 ± 0.23	3.73 ± 0.00

Table 6. Elemental composition of swine diets fed during the time frame of this study (mg/kg, μ ± 1 SD).

Diet/Slurry type (N=12)	Al	Ca	Cu	Fe	Mg	Zn	Co	Cr	Mn	Ni	K	Na
Gestation	165 ± 21.2	15000 ± 2828.4	30 ± 0.0	385 ± 91.9	2000 ± 0.0	< 0.01 ± 0.0[a]	10 ± 0.0	< 0.01 ± 0.0	100 ± 0.0	20 ± 0.0	5000 ± 0.0	2000 ± 0.0
Farrowing	170 ± 28.2	17500 ± 2121.3	35 ± 7.0	260 ± 14.1	2000 ± 0.0	< 0.01 ± 0.0	5 ± 7.0	< 0.01 ± 0.0	120 ± 0.0	10 ± 0.0	8500 ± 707.1	3000 ± 0.0
Nursery	14.1 ± 176	11500 ± 707.1	190 ± 42.4	355 ± 35.3	2000 ± 0.0	100 ± 14.1	< 0.01 ± 0.0	< 0.01 ± 0.0	50 ± 0.0	25 ± 7.0	8000 ± 0.0	2000 ± 0.0
Grow/Finish	176 ± 0.0	10667 ± 471.6	10 ± 0.0	340 ± 38.1	1836 ± 235.4	< 0.01 ± 0.0	6.67 ± 0.0	< 0.01 ± 0.0	38.5 ± 2.1	8.34 ± 2.3	5667 ± 471.6	1333 ± 0.0

[a] = Minimum detection limit (MDL).

Table 7. Swine waste slurry and effluent solids (SS, TSS) concentrations, related reduction efficiencies, solids dry weight, and pH values (Mean ± 1 SD for all four slurry and effluent types).

Swine Waste Slurry/Effluent Type (n = 8)	**Settleable Solids (SS) (ml/L)**	**SS Conc. Reduction (%)**	**Suspended Solids (TSS) (mg/L)**	**TSS Conc. Reduction (%)**	**Solids Dry Weight (SDW) (%)**	**pH**
Raw unprocessed slurry (RS)	788 ± 329	NA[1]	1,782 ± 324	NA	3.65 ± 0.06	7.6 ± 0.1
Gravity screen-roll press separated effluent (SE)	322 ± 232	59.1	1,619 ± 383	9.1	2.65 ± 0.02 [a]	7.6 ± 0.3
PAM-assisted gravity belt separated RS effluent (BE1)	MDL[2] [a]	> 99	94.8 ± 52.3[a]	94.7	0.19 ± 0.01[b]	7.7 ± 0.2
PAM-assisted gravity belt separated SE effluent (BE2)	MDL [a]	> 99	98.0 ± 39.6 [a]	93.9	0.16 ± 0.01[b]	7.7 ± 0.2

[1] (NA) = Not applicable.
[2] (MDL) = Below minimum detection limit of 0.1 ml/L
[a,b] = Means within a column with different superscript letters differ significantly from RS ($p \leq 0.05$)

Table 8. Swine waste slurry and effluent treatment COD, P, and N concentrations, and related reduction efficiencies (Mean ± 1SD for all four slurry and effluent types)

Swine Waste Slurry/Effluent Type (n = 8)	**Chemical O_2 demand (COD) (g/L)**	**COD Conc. Reduction (%)**	**Phosphorous (P) (%)**	**P Conc. Reduction (%)**	**Nitrogen (N) (%)**	**N Conc. Reduction (%)**	**N:P Ratios**
Raw unprocessed slurry (RS)	127 ± 58.8	NA[1]	1.29 ± 0.90	NA	5.46 ± 1.61	NA	4.23
Gravity screen-roll press separated effluent (SE)	104 ± 55.2	18.2	1.07 ± 0.70 [a]	17.0	4.35 ± 2.06	20.3	4.06
PAM-assisted gravity belt separated RS effluent (BE1)	19.6 ± 3.9[a]	84.7	0.10 ± 0.02 [b]	92.2	1.12 ± 0.45 [a]	79.5	11.20 [a]
PAM-assisted gravity belt separated SE effluent (BE2)	28.2 ± 4.0 [a]	63.0	0.05 ± 0.04 [b]	96.1	1.27 ± 0.49 [a]	70.8	25.40 [a]

[1] (NA) = Non-applicable

[a,b] = Means within a column with different superscript letters differ significantly from RS ($p \leq 0.05$)

Table 9. Comparative operation costs for a gravity screen-roll press separator (SE) and a PAM-assisted gravity belt thickener system (BE) for separating swine slurry.

Separator type	Operation rate (gpm)	Calculated cost of slurry separation[3]
Gravity screen-roll press[1]	60.0	.29¢:1000g
PAM gravity belt thickener[1]	27.4	1.13¢:g
PAM gravity belt thickener[2]	50.3	.75¢:g

1 = Reflects actual raw slurry flow rate used in this study
2 = Assumes a theoretical increase in raw slurry flow rate of 83.5%
3 = Calculated costs based on $0.10 Kilowatt hour electricity charge, 10 hours operation per day, 365 days/year, yearly maintenance charges at 2% of equipment cost, labor at $10/hour, and straight-line depreciation over 15 years of equipment operation with no salvage value
4 =Assumes equipment purchase cost of $10,000.00
5 = Assumes equipment purchase cost of $200,000.00 and PAM costs of $4.40/kg

Table 10. Effect of Polyacylamide Treatment on Selected Volatile Organic Acids Concentrations (ug:g) Collected from Swine Slurry (n=12)

	Type of Slurry:							
	Lactation				Grower-Finisher			
Compound	Untreated[1]	Separated Effluent[1]	Standard Error	% Change	Untreated[1]	Separated Effluent[1]	Standard Error	% Change
Acetic Acid	5082.10	2388.75*	1116.74	53	383112.62	19892.36*	5400.05	48
Propanoic Acid	638.90	446.74*	71.48	30	3838.72	2164.28*	244.62	44
Isobutyric Acid	87.99	43.13*	2.81	51	588.87	209.47*	83.33	64
Butyric Acid	396.96	243.02*	34.46	39	3113.42	1709.13*	145.12	45
3-methylbutyric Acid	116.06	55.30*	6.79	52	465.03	183.08*	39.91	61
Pentanoic Acid	57.05	41.53*	7.67	27	418.74	238.63	16.77	43
2-ethylbutyric Acid[2]								
Hexanoic Acid	38.29	27.82*	4.63	27	341.11	273.27*	16.81	20
Phenol	124.32	1.16*	14.14	99	186.18	4.54*	27.43	98
4-methylphenol	746.05	19.73*	61.59	97	2040.77	54.31*	257.2	97
4-ethylphenol	117.24	4.12*	13.34	96	195.86	9.62*	24.02	95
4-tert-butylphenol[2]								
Indole	1.26	0.23*	0.21	82	1.95	0.86*	0.25	56
3-methylindole	5.05	1.64*	0.22	67	19.03	9.53*	1.99	24
2-methylindole[2]								
Phenylacetic Acid	163.19	22.73*	37.75	86	1435.68	1102.78	180.57	23
3-phenylpropanoic Acid	48.74	17.82*	10.87	63	361.22	337.78	52.69	6.5

[1] Concentration mean.

[2] Below detection limits.

* Within a subheading, means within a row with different superscripts differ ($p < 0.05$).

Table 11. Odor Activity Values for Selected Volatile Organic Acids From Swine Slurry Odor Activity Value

Compound	Detection Threshold mg:L	Gestation/Lactation		Grow/Finish	
		Raw Slurry	Effluent	Raw Slurry	Effluent
Acetic Acid	22.0[a]	231.0	108.6	1741.5	904.2
Propanoic Acid	2.2[a]	290.4	203.1	1744.9	983.8
Isobutyric Acid	8.1[b]	10.9	5.3	72.7	25.9
Butyric Acid	1.3[a]	305.4	186.9	2394.9	1314.7
3-methylbutyric Acid	0.25[a]	464.2	221.2	1860.1	732.3
Pentanoic Acid	1.2[a]	47.5	34.6	348.0	198.9
Hexanoic Acid	0.036[a]	1061.1	772.8	9475.3	7590.8
Phenol	5.9[c]	21.1	0.2	31.6	0.8
4-methylphenol	0.0027[a]	276,314.8	7307.4	755,840.7	20,114.8
4-ethylphenol	1.0[d]	117.2	4.1	195.9	9.6
Indole	0.021[a]	60.0	11.0	92.9	41.0
3-methylindole	0.003[a]	1683.3	546.7	6343.3	3176.7
Phenylacetic Acid	10.0[e]	16.3	2.3	6343.3	110.3
3-phenylpropanic Acid	-[f]	-	-	-	-

[a] Reference for odor detection threshold value is Karagul-Yuceer, Y., Vlahovich, K.N., Drake, M.A. and Cadwallader, K.R. 2003. Characteristic aroma components of rennet casein. J. Agric. Food Chem. (forthcoming).

[b] Reference for odor detection threshold value is Salo, P. 1970. Variability of odour thresholds for some compounds in alcoholic beverages. J. Sci. Food Agric. 21: 597.600.

[c] Reference for odor detection threshold value is Baker, R.A. 1963. Threshold odors of organic chemicals. J. Am. Water Works 55: 913-916.

[d] Reference for odor detection threshold value is Williams, A.A. 1974. J. Inst. Brew. 80: 455-470.

[e] Reference for odor detection threshold value is Maga, J.A. 1973. Taste threshold values for phenolic acids which can influence flavor properties of certain flours, grains, and oilseeds. Cereal Science Today. 18: 326-330.

[f] No odor detection threshold value available.

REFERENCES

Association of Analytical Chemists (AOAC), 1975 Official Methods of Analysis, 12th ed. AOAC, Washington, DC.

Audouin, V., Bonnet, F., Vickers, Z. and Reineccius, G.A. 2001. Limitations in the use of odor activity values to determine important odorants in foods. In *Gas Chromatography-Olfactometry: The State of the Art,* Leland, J.V., Schieberle, P., Buettner, A. and Acree, T.E. (Eds.). ACS Symposium Series 782, Amercian Chemical Society, Washington, D.C., pp. 56-171.

Buelna, G., Bhattarai, K., de la Noue, J., Taiganides, E., 1990. Evaluation of various flocculants for the recovery of algal biomass grown on pig-waste. Biological Wastes 31 (3), 211-222.

Burkholder, J.M., Mallin, M., Glasgow, H., Larsen Jr., L., McIver, M., Shank, G., Deamer-Melia, N., Briley, D., Springer, J., Touchette, B., Hannon, E., 1997. Impacts to a costal river and estuary from rupture of a large swine waste holding lagoon. Journal of Environment Quality 26 (6), 1451-1466.

Cullum Jr., R., 1988. Sedimentation phenomena in swine waste slurries: model development. Transactions of the ASAE (American Society of Agricultural Engineers) 31, 1760-1766.

Eaton, A. (ed.), 2000. Standard Methods for the Examination of Water and Wastewater, 20th ed. American Public health Association (APHA), American Water Works Association (AWWA), Water Environment Federation (WEF).

Fernandes, l., E. McKyes, and L. Obidniak. (1988). Performance of a continuous belt microscreening unit for solid liquid separation of swine waste. Canadian Agricultural Engineering, 30(1):151-55.

Fransen, N., Bert, A., Bijker, P., 1995. Utilization for fermented, flocculated poultry sludge as a feed constituent for pigs. Poultry Science 74, 1948-1960.

Graves, R.E. and J. Clayton. (1972). Stationary sloping screen to separate solids from dairy cattle manure slurries. Paper No. 72-951. American Society of Agricultural engineers (ASAE), St. Joseph, MI, USA.

Glerum, J.L., g. Klomps and H. Poelma. (1971). The separation of solid and liquid parts of pig slurry. In: Livestock Waste Management and Pollution Abatement. Publication No. PROC 2-71. American Society of Agricultural Engineers (ASAE), St. Joseph, MI USA.

Hach Company, 1992. Water Analysis Handbook. Hach Company, Loveland CO.

Hammer, M., Hammer Jr., M., 2001. Water and Wastewater Technology. Prentice Hall Publishers, Upper Saddle River, NJ.

Hatfield, J.L., Stewart, B. (Eds.), 1998. Animal water Utilization: effective use of manure as a soil resource. Ann Arbor Press, Chelsea, MI.

Haywood, F., 1997. Handling liquids and solids on hog farms. Biocycle 38, 55-57.

Hill, D.T. and J. Baier. (2000). Physical and chemical properties of screened-flushed pig slurry waste. Journal of Agricultural Engineering Research, 77(4):441-48.

Kelley, T.R., Walker, P., Smiciklas, K., 1999. Bacterial concentration reduction in swine waste amended livestock feed using a single-screw dry-extrusion process. Bioresource Technology 75 (30), 189-195.

Kelley, T.R., Walker, P., Smiciklas, K., 1999. Survival of culturable bacteria during co-composting of institutional, agricultural, and municipal solid waste. Environmental Practice. 1 (3), 162-167.

Koegel, R.G., R. Straub, W. Delzer, and J. Kim. (1990). Design of a reciprocating press for solid-liquid Separation of dairy waste. In: Agricultural and Food Processing Waste. Publication No. 05-90.

Koh, M., Shen, T., Tseng, S., 1995. Effect of separation and mixing process on the production and properties of sludge from swine waste water after anaerobic fermentation. Journal of the Chinese Society of Animal Science.

Lee, S.J., Park, K., Koopman, B., 1997. Effect of fermented swine wastes on nutrient removal in sequencing batch reactors. Water Research 31 (7), 1807-1812.

Martinez, J., Burton, C., Sneath, R., 1995. A study of the potential contribution of sedimentation to aerobic treatment processes for pig slurry. J. of Agri. Engin. Res. 61:87-96.

Merna, P., (2000). Owner, Merna Farms; Merna, IL, personal communication.

Ndegwa, P.M., Zhu, J., Luo, A., 2001. Effects of solid levels and chemical additives on removal of solids and phosphorous in swine manure. J. of Env. Engin.127 (12), 1111-1115.

Prince, T. J. and D. Hill. (1985). The nutritional value of swine waste solids: effects of mechanical screening on nutrient composition. In: Agricultural Waste Utilization and Management: Proceedings of the Fifth International Symposium on Agricultural Wastes. Chicago, IL.

Rhyner, C.R., Schwartz, L., Wenger, R., Kohrell, M., 1995. Waste Management and Resource Recovery. CRC Lewis Publishers, Boca Raton, FL.

Ritter, W.F., Chirnside, A., 1990. Impact of animal waste lagoons on groundwater quality. Biological Wastes 34 (1), 39-54.

Rorick, M.B., d. Warburton, S. Spahr, and D. Day. (1980). Performance of a perforated pressure roller solid/liquid separator on dairy manure. In: Livestock Waste: A Renewable Resource. Publication No. 2-81. American Society of Agricultural Engineers (ASAE), St. Joseph, MI, USA.

Salvato, J., 1992. Environmental Engineering and Sanitation. John Wiley & Sons, New York, NY.

Sanks, R., 1978. Water Treatment Plant Design for the Practicing Engineer. Butterworth Publishers, Boston, MA.

Severin, B.F., H. Grethlein. (1996). Laboratory simulation of a belt press dewatering: application of the darcey equation to gravity drainage. Water Environment Research, 68:359-69.

Shirley, R. and A. Butchbaker. (1975). A rotating conical screen separator for liquid-solid separation of beef waste. In: Managing Livestock Wastes. Publication PROC 2-75. American Society of Agricultural Engineers (ASAE), St. Joseph, MI, USA.

Shutt, J.W., R. White, E. Taiganides, C. Mote. (1975). Evaluation of solids separating devices. Managing Livestock Waste, Publication PROC 2-75, American Society of Agricultural Engineers (ASAE), St. Joseph, MI, USA.

Sievers, D.M., Jenner, M., Hanna, M., 1994. Treatment of dilute manure wastewaters by chemical coagulation. Transactions of the American Society of Agricultural engineers 37 (2), 597-601.

Sneath, R.W., 1988. Centrifugation for separating piggery slurry. Economic effects on aerobic methods of odour control. Journal of Agricultural Engineering Research. 39, 199-208.

Statistical Package for Social Sciences. (1988) Version 3. Chicago SPSS, Inc.
Tseng, S., Tsai, M., 1996 Study of chemical precipitation for phosphorous removal in swine wastewater. Journal of the Chinese Institute of Environmental Engineering 6 (4), 4430451.
Vanotti, M.B., Hunt, P., 1996. The use of polymers for nitrogen removal in swine wastewater: PAM and encapsulated nitrifier technologies. In: Proceedings of the Technical Conference on Water Quality. North Carolina State University, Raleigh, NC, pp. 116-120.
Van den Dool, H. and Kratz, P.D. 1963. Generalization of the retention index system including linear temperature programmed gas-liquid partition chromatography. J. Chromatogr. 11: 463-471.
Voss, R.D., (1993). Corn Nutrient Deficiencies and Toxicities in Crop Plants. APR Press, St. Paul, MN. P. 12.
Zhou, Q., Wintersteen, C.L. and Cadwaller, K.R. 2002. Identification and quantification of aroma-active components that contribute to the distinct malty flavor of buckwheat honey. J. Agric. Food Chem. 50: 2016-2021.

Aerobic Thermophilic Digestion: A Technical and Practical Option for Swine Manure Management

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SCOPE

This paper is a review of the work accomplished in the Swine Odor and Waste Strategic Research Initiative (SOWM SRI) of Illinois Council on Food and Agricultural Research (C-Far) during state fiscal years 99, 00, 01, 02 and 03. The format of the paper will be topical in nature and not necessarily chronological. We have pursued research objectives in a number of years and the topic and current position will be discussed here. Also we were fortunate to have five related research projects underway, essentially in parallel and some of the findings occurred in the structure of these projects, strictly not this SOWM SRI. However, the bulk of the findings will be here reported with references to the other projects when pertinent. Table 1 will offer the title and supporter of these other projects and will serve for this paper as a reference table of other supported work.

EQUIPMENT DEVELOPMENT—2 L BIOCALORIMETER, 1000 GAL (3800 L) BATCH AND SEMICONTINUOUS PILOT PLANTS

While encompassing a fairly short time frame, a goal of the C-Far SRI's (T-1, P-1,2) was to bring technology to solve field problems as soon as possible. With this in mind, but realizing that a basic understanding of the process is needed, we began in 2000 with a 2 L biological calorimeter to measure and confirm 1) heat energy as COD was present and consumed from swine waste at high rates, and 2) the heat produced is of a temperature and quality that it may be used elsewhere on the farm for an economic savings.

Swine waste was obtained from a local producer's gestation, delivery and nursery barn. This unit used a scraper system and that coupled with the sampling time (early January) led to a concentrated material (15% total solids and about 14% COD). The producer also allowed his gestating sows outside and there is some amount of undigested grass in the waste. The waste aged for one week total in the producer's facility. These samples were mixed and split into samples of about 1 liter and were refrigerated until needed for the biocalorimeter runs.

Background runs with water enabled us to quantify the biocalorimeter's heat loss rate and the water cooling rates. These values were essential for calculating the heat balance on the biocalorimeter. Waste samples were ground in a blender to reduce the particle size of the grass blades and allow operation in our small 1.5 liter system. A number of valuable runs with the

biocalorimeter verified the ability to produce heat and the ability to remove the Chemical Oxygen Demand, COD, a measure of the waste's fuel content.

Table 1. Ongoing and related research projects

Project	Title	Schedule	Source	Thrust
1-SOWM-SRI	Advances in Aerobic Thermophilic Treatment for Energy Production from Swine Wastes	07/1998 to 6/30/2003 (no cost ext. to 2004)	SOWM-SRI, Ill. C-Far	Energy recovery and odor removal from swine manure
2-FS-SRI	Bacterial Pathogen and Antibiotic Content of Organic Food Fertilizer Produced...Swine Waste	12/2000 to 6/30/2003 (no cost ext to 2004)	Food Safety SRI, Ill. C-Far	1.Survivability of bacterial pathogens and three introduced antibiotics in aerobic thermophilic-treated wet or dry product 2. Growth potential of vegetables on dry product
3-DCEO/DOE	Heat Production from Air-Therm Treatment of Swine Waste	1/2001 to 6/2003	Ill. DCEO and US DOE	Determine economical method to utilize heat produced in the warm weather months
4- Ill EPA and USEPA	Evaluation of Treated Swine Waste Application	3/2000 to 6/2003	Ill. IEPA and USEPA (319 grant)	1.Determine N and P runoff from addition of wet treated product 2.Evaluate corn growth on wet treated product
5-Ill Attorney General's Office	Full-Scale Demonstration for Odor Reduction on an Illinois Hog Farm	7-2002 to 6-2005	Ill. Attorney General's Office	Design, construct and monitor aerobic thermophilic system for odor removal and energy production

1000 Gallon Batch Pilot Plant. Having established the efficacy of the process, it became important to operate the system at a scale from which the design of a full-scale system became possible. This scale would enable projections about odor, phosphorus removal and such. The original concept was for a batch process.

The system was comprised of a modified 1000 gal (3800 L) SS tank, a ¾ hp top-mounted variable-speed agitator, internals of a two coil heat exchangers and an air diffuser, a Roots-type blower with the capability of tank air recycle, a sulfuric acid offgas scrubber and other various pumps, thermocouples, sensors, and controllers to enable operation. A computer data acquisition system was available. This system was run for 17 batches of about 800 gal each. Heat balances

as well as composition changes were analyzed and interpreted from this work. Some of the results will be presented later.

1000 gal. Semi-continuous Pilot Plant. After performance was verified on batch operation at the pilot scale, we turned our attention to a full-scale design. For this design, a semi-continuous system was preferred in order to even out the heat production which was cyclic in the batch configuration. We also expected other operating advantages and felt that the pork producer would prefer a system that was essentially self-operating. Since there was some question as to whether the semi-continuous system would produce the same results as the batch system, SOWM-SRI management suggested that we pilot the semi-continuous system and this became our focus for the last phases of Table 1, Project 1. We needed more space than was available where the batch system was installed and successful obtained a new building built at the SIU Swine Center to house the Semi-continuous system. This building was completed in the Spring of 2002 and we then spent several months to install the semi-continuous system and its different sensor and control schemes. By Winter of 2002 we were operational and completed three runs before the end of the project in Summer 2003.

HEAT BALANCES FROM THE EXPERIMENTS

The 2 L Biocalorimeter was operated a number of times. Three runs were selected to show the heat balance results (Figure 1-3) and also some compositional changes in pH and Ammonia (Figure 4). Table 2 presents the operating conditions for the three runs presented.

Table 2. Experimental operating data from 2 L biocalorimeter

Run Number	Initial Solids (wt %)	Temperature (C)	Air Flow (mL/min)
3	6.3	57	590
5	9.7	55	590
6	9.3	57	590

Qualitative "smell tests" indicate that the odor was rapidly removed from the waste, as expected from the results of other investigators. When the pH rose to 8.0, more ammonia odor was identified. Run 3 showed a relatively high and rapid heat production rate over just 3 days, while Run 5 showed a more gradual heat production rate through 6 days. This might result from the higher solids concentrations of Run 5 affecting either the oxygen transfer rates or the higher levels of ammonia found in a more concentrated mixture. Higher levels of ammonia might lead to increased ammonia toxicity for the microbes, reducing the heat production rates. Ammonia concentrations and pH in Runs 5 and 6 are shown in Figure 4. These levels initially increase, then decrease. In the case that ammonia air strips, it was easily recovered through the use of a scrubber applied to the exhaust air.

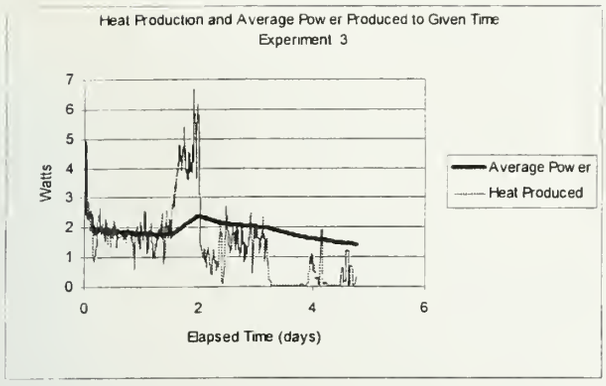


Figure 1. Experiment 3.

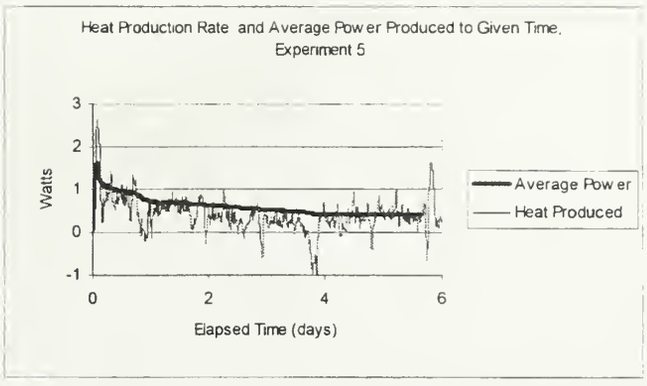


Figure 2. Experiment 5.

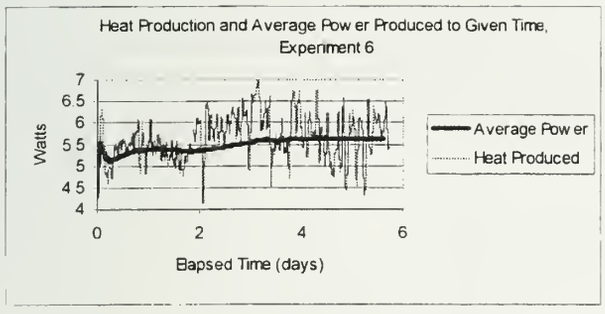


Figure 3. Experiment 6.

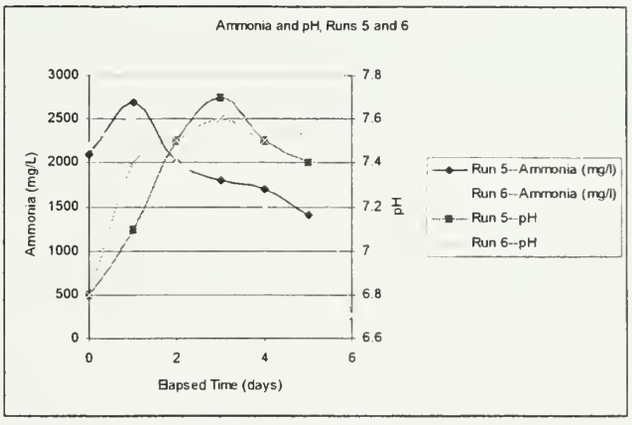


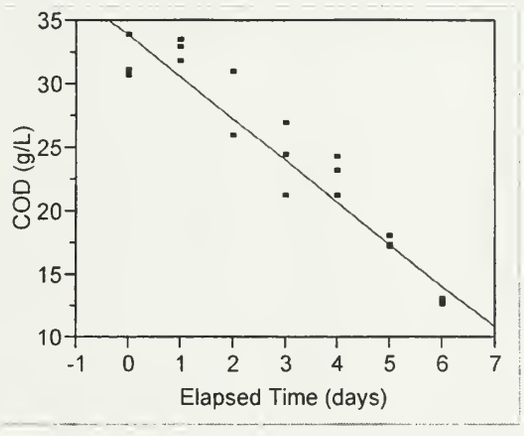
Figure 4. Ammonia and pH.

A model concept batch system was envisioned at this point with an energy balance as shown in Table 3. A major factor in the design is the assumption used for the concentration and volume of hog waste produced. Using the following literature values on waste composition and production rate; energy efficiency features under cold (-10 °C) air temperatures for a farm with 1000 swine (13.15 lbs solids animal^{-1} day^{-1} and 3.84 gal liquid animal^{-1} day^{-1}); An estimate of heat production is possible. Later estimates reconsidered the technology with lower level of waste production and still found the concept appealing.

Table 3. Energy balance on swine manure in cold weather

Heat Sources and Sinks	Heat (Btu/hr)
Released due to aerobic biooxidation	910,000
Heat initial waste to 55°C	-19,000
Lost to ground	-6,500
Lost to air at cover	-50,000
Lost in aeration air	-318,000
Lost in heating makeup water	-16,000
Net Energy Produced	500,500

In the Batch Pilot Plant, specific results of COD removal for two runs are shown in Figures 5 and 6. High COD removal rates are key to both energy production and stable odor removal. Form an energy production standpoint we have determined that total biological energy production is of the order of 13.9 Mj/kg COD removed. Figure 5 presents results from Batch Pilot Run 9 with an air flow without air recycle of about 16 scfm and a starting solids concentration of about 3%. Figure 6 presents results from Batch Pilot Run 11 with an air flow of about 12 scfm and air recycle, with a starting solids concentration of near 1%.

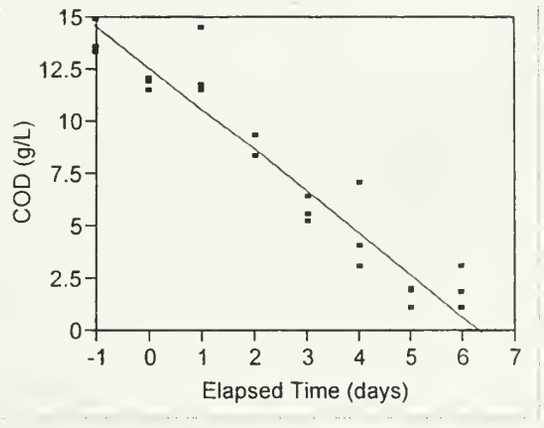


COD (g/L) = 33.928571 - 3.2952381 Elapsed Time (days)

Figure 5. COD Removal results from batch pilot run 9.

Run 9 shows a COD removal of 58% over the six days of operation and Run 11 yields over 90% removal for the operational period.

Table 4 presents a summary of the performance of energy production for the Batch Pilot Runs (runs up to Run 7 were rejected because of an inferior aeration scheme). Biological heat production may be stated in terms of the solids production rate of, say 100 animals to help in comparisons between system scales and to partially alleviate the changing effects of feed composition.



COD (g/L) = 12.636905 - 1.9821429 Elapsed Time (days)

Figure 6. COD Removal results from batch pilot run 11.

Table 4. Batch system operating conditions and performance after six days—gestation building waste

Run No.	Air Feed (% recycle reactor offgas)	Ave. fresh air (cfm)	Initial Total Solid (%)	Initial COD (g/l)	COD removal (%)	Solid removal (%)	Ave. biological heat production rate by COD consumption (kW/100 hogs)
7	0	12.09	4.267	51.4	47.3	43.7	6.5
8	0	16	1.583	23	52.7	36.6	8.9
9	0	16	2.697	33.9	61.1	35.7	8.0
10	0	10	4.587	64	33.8	23.0	5.5
11	40	10	1.037	11.5	78.6	19.7	10.1
12	40	9.47	3.460	46	52.0	37.6	7.9
13	60	7.6	3.703	61.3	50.0	12.3	10.3
14	40	9.66	3.313	27	69.7	28.5	6.5
15	60	7.57	2.517	41.7	43.0	10.2	8.2
16	60	6.21	1.537	22	60.0	17.9	8.6
17	40	10.57	1.400	23.2	51.6	16.8	9.8

These data permit the testing of the hypothesis that air recycle might reduce the biological heat production rate. Figure 7 shows the groupings by recycle rate and a related statistical analysis shows no difference in the heat production rate as recycle is increased.

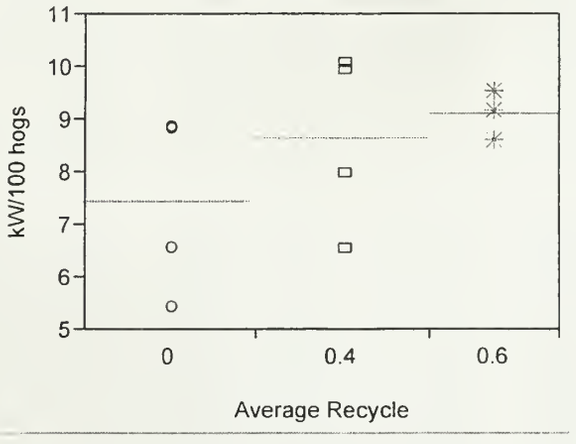


Figure 7. Effect of air recycle on biological heat production

The results from the Semi-continuous Pilot runs are not all currently available, However one run with finishing waste and having a 6-day Residence Time is shown in Table 5. The Biological heat production may be calculated from COD and solids concentrations and is shown in the final column. We must caution, however that the sampling and measurement of initial solids assumes a complete mixing when the sample was taken and vigorous shaking and uniform sampling when the sample is analyzed. The Feed tank was mixed at a rate of about 0.5 hp/ 1000 gal, but some separation of solids may have occurred before sampling. This calculated value should be taken as an estimate. These values are comparable to the middle column of Figure 7 and seem to be favorable with this Semi-continuous Pilot Run having a higher biological heat production compared to the Batch Pilot Runs.

ODOR REMOVAL

The offgas of Pilot Batch Run 17, after the system achieved initial temperature and before ammonia scrubbing, was collected according to U of I SOWM protocols and transported to Dr. Brewer's lab for olfactometry analysis within 24 hours. Samples analyzed within hours of being taken show over 90% reduction in the odor detection threshold (Figure 8). Liquid samples taken simultaneously were immediately frozen and later transported to Dr. Cadwallader's lab at U of I for analysis of many organic odor-causing compounds. Figure 13 shows most compounds are removed to the detection threshold after several days in the batch reactor. Even indole and skatole were removed to over 90% during the 6 day batch run. Since high concentrations are emitted for the first few days in a batch system, after startup of a week to ten days, semi-continuous operation with similar residence times would have a constant, low concentration of odorants in the liquid and would be expected to maintain relatively constant, but low odor emissions. We were unable to measure odor in the semicontinuous pilot runs because of budget and timing constraints in FY-03.

Table 5. Semi-continuous system operating conditions and performance with a six day residence time—finishing building waste

Date	Air feed (% recycle)	Ave fresh air (cfm)	Nominal residence time (days)	Total solid (%)	COD (g/l)	COD removal (%)	Solid removal (%)	Heat production by heat balance (kW)	Heat Production By COD (kW/100 hogs)
5/29/2003 Feed tank				1.19	30.9				
5/29/2003	55.6	6.7	6	2.06	36.0	0	0	N/A	0
5/30/2003	45.4	7.7	6	1.89	31.7	11.9	0.08	2.02	43.5
5/31/2003	38.6	9.7	6	1.85	21.2	41.1	10.2	3.13	12.3
6/01/2003	37.2	9.3	6	1.61	18.2	49.4	21.8	1.92	14.7
6/02/2003	45.8	9.0	6	1.46	19.6	45.5	29.1	1.58	13.6
6/03/2003	38.2	8.1	6	1.40	15.2	57.8	32.0	3.35	17.3
6/04/2003	47.9	9.9	6	1.20	17.3	51.9	41.7	2.20	15.5
6/05/2003	50.3	9.1	6	1.04	19.8	45.0	49.5	0.56	13.4
6/06/2003	34.0	10.1	6	1.21	16.5	54.2	41.3	3.15	16.2
6/07/2003	42.1	9.6	6	1.15	16.6	53.9	44.2	1.66	16.1
6/08/2003	44.3	8.8	6	1.15	15.3	57.5	44.2	2.83	17.2
6/09/2003	49.5	5.0	6	1.09	12.8	64.4	47.1	2.36	19.2
6/10/2003	59.7	4.8	6	1.16	12.7	64.7	43.7	2.10	19.3
6/11/2003	63.2	5.0	6	0.92	11.8	67.2	55.3	N/A	20.1
6/12/2003	49.0	7.9	6	1.11	12.4	65.5	46.1	3.66	19.6

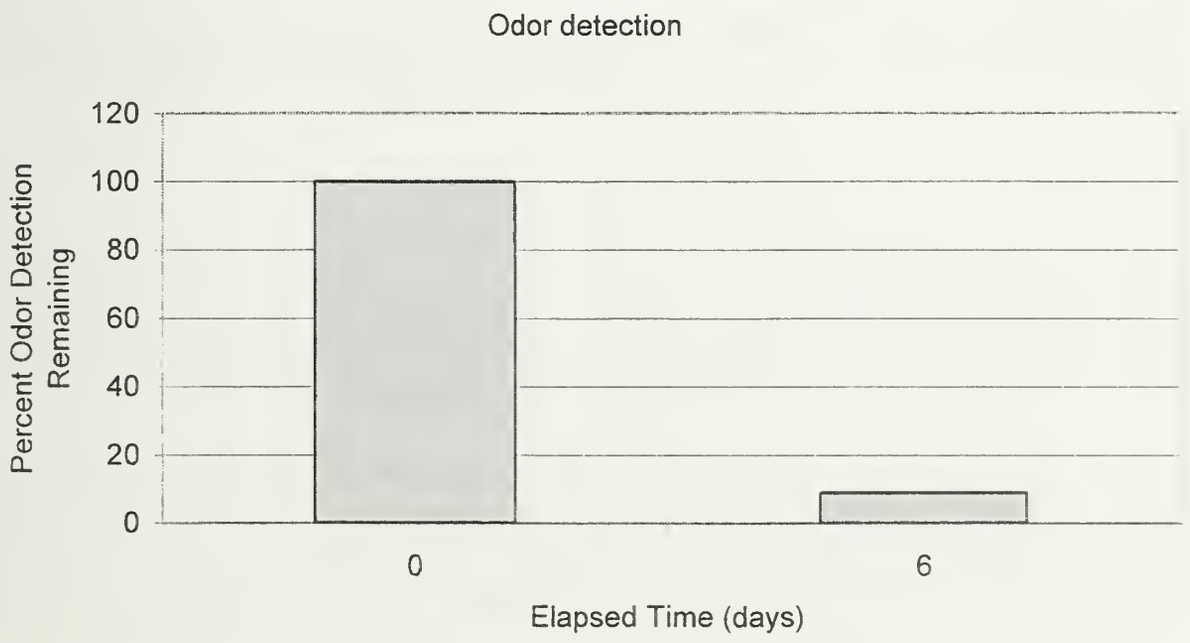


Figure 8. Odor detection removal by olfactometry in batch pilot run (Analysis By Dr. Brewer, UIUC.

However another semicontinuous aerobic thermophilic pilot run on finishing waste from Silsoe, UK using the olfactometer odor analysis method has reported over 80% odor removal at the pilot stage.[1]

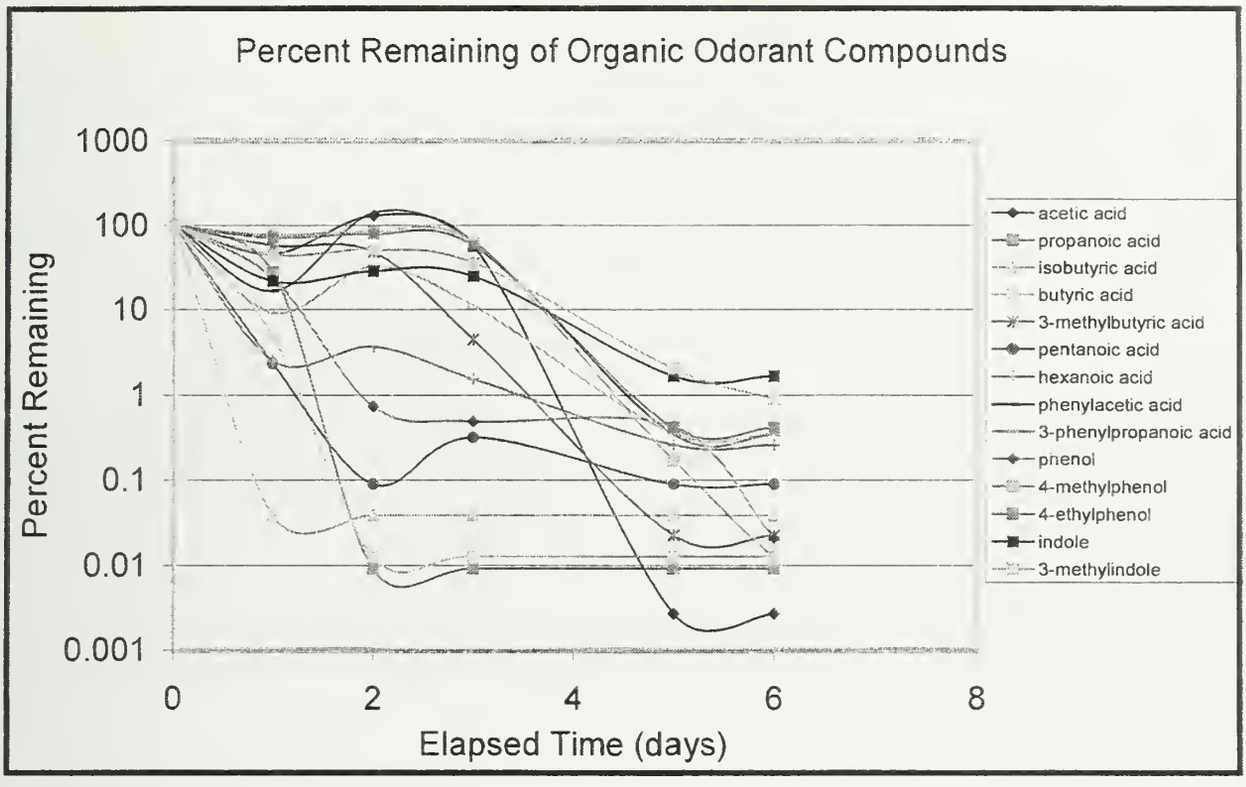


Figure 13. Removal of Organic Odor Compounds in Batch Pilot Aerobic Thermophilic Treatment. Analysis by Dr. Cadwallader, UIUC.

NITROGEN REMOVAL

In the batch pilot runs, about one forth of the nitrogen in the raw manure is converted to ammonia in this process. In a batch system, a surge of ammonia and its associated odor may be expected from the first few days in the run. In a continuous system after startup, the ammonia would be emitted more or less constantly during operation.

While we seldom measured ammonia directly in the pilot runs, we did determine that essentially no nitrification occurs at the 55°C reactor temperature and so nitrogen reduction in the reactor product produces ammonia. In a Semi continuous Pilot Run with a long residence time (~14 days), approximately double the ammonia was formed as compared to a semi-continuous run of 6 days residence time.

We have included an acid scrubber in past designs to remove this ammonia and lower the odor while recovering the nitrogen as ammonium sulfate. There are several drawbacks to making

[1] P.W. Sneath, C.H. Burton, A.B. Williams. 1992. Continuous Aerobic Treatment of Piggery Slurry for Odour Control Scaled up to qa Farm-Sized Unit. J. Agric. Engrg, Res. 53.89-92.

ammonium sulfate including the pork producer having to purchase and store large quantities of sulfuric acid, having to store the ammonium sulfate product and most importantly, when applied to soil as a fertilizer, ammonium sulfate becomes acidic and the producer is required to frequently lime the fields.

We have decided to reduce the ammonia odors, but convert the ammonia to nitrogen gas. This is a new component of our project and was not able to be tested during the challenging budgets of FY-03. We will use a scrubber to absorb the ammonia, but will foster a microbial film in the scrubber to nitrify or convert the ammonia to nitrate. Then after some additional swine manure is added and excess oxygen is removed, the nitrates will be denitrified to nitrogen gas. We will reduce the ammonia odor, but will loose the nitrogen fertilizer value in the reactor product.

PHOSPHORUS REMOVAL

During most of this project we have been documenting the apparent loss of phosphorus during the batch aerobic thermophilic process. Under oxidizing conditions, no actual loss of phosphorus from a batch system is expected, although some volatile loss is possible under anaerobic conditions. We have continued to document this observation and results are shown for 7, 1000-gal batch pilot runs and two semi-continuous pilot runs (about 6 days residence time) in Figure 14. A third semi-continuous run at long residence times (12-14 days) failed to show a removal (showing an apparent increase of P), but reactor sampling issues may have been a concern.

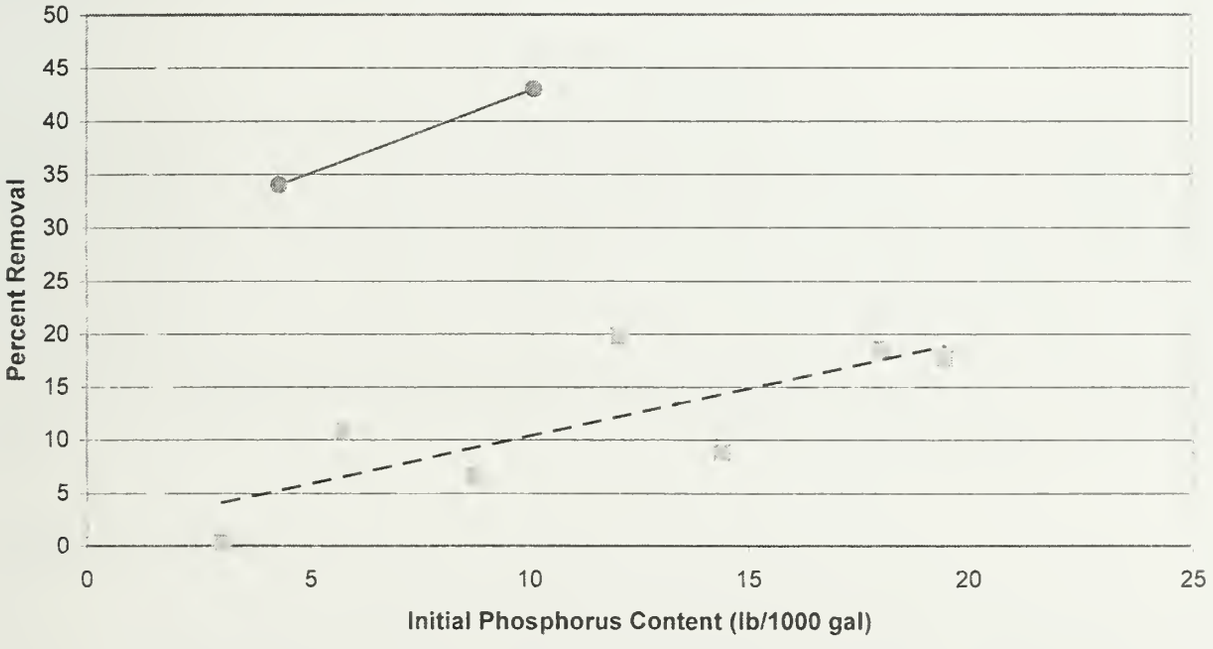


Figure 14. Percent removal of phosphorus v. initial phosphorus content. One data point each for the semi-continuous (Solid Line) and batch runs (Dotted Lines) showed apparent production of phosphorus and were treated here as outliers.

In batch pilot runs, the effect of apparent P reduction is stronger when the initial concentrations of phosphorus (the initial solids concentration) are high and could be over 20% at typical swine manure strengths. One hypothesis is that no phosphorus is actually being removed from the reactor, but it is changed in form to an insoluble inorganic form resistant to the phosphorus analytical method (nitric-perchloric acid digestion with ICP elemental measurement). Along these lines we have confirmed that at least some of the phosphorus is being converted to the mineral struvite (a magnesium ammonium phosphate). Our evidence is x-ray diffraction identification of a white crystalline material found on the air diffuser. We have not yet done the confirmatory step of adding a known amount of struvite to fresh and treated manure to check if the material is accounted for in the manure analysis. We were unable to continue this in FY-03. The semi-continuous runs show apparently higher P removal than the batch pilot runs. The cause of this is unclear, however the semicontinuous runs had more throughput of feed during a given experiment and this may have affected the formation of an insoluble inorganic phosphorus compound leading to possibly higher deposits in the reactor itself.

In associated work sponsored by IEPA/EPA (Table 1, Project 4), we tracked P from treated manure in runoff from statistically-designed corn plots, while at the same time taking Bray P1 soil analyses. At the end of year two, a statistically significant ($p=0.05$) lessening of the treated reactor product as seen in plot runoff was compared to anaerobic lagoon-applied waste. The amount of P applied at the beginning of the growing season was standardized to 100 kg P/ ha. Unfortunately some event or series of events occurred in the third growing season radically increasing P in the runoff from all plots including the untreated control. After this, no significant difference was seen in the reactor product plots for the project as a whole. Budget and timing constraints forced us to stop this work and we are still interpreting the results.

PATHOGEN REMOVAL

This area has been supported by the C-FAR Food Safety Strategic Research Initiative (Table 1, Project 2). Studies on six zoonotic or human pathogens were done in a 3 liter reactor by spiking in the pathogens and on numerous 1000-gal batch pilot system runs with the organisms naturally present. A summary table of initial results and results at 6 days after heating and air initiation are seen in Table 6. Most pathogens studied were completely removed to detection limits of 1 cell-forming unit/ml with 2 having 4-5 logs removal, but persisting at low levels (10-100 CFU/ml). *C. perfingens* is known to require high dosages for infection (~10^8 CFU/g food)[2]. Well over a metric ton of treated reactor product would have to be ingested for food poisoning to occur.

Antibiotic Removal

This work was also supported by the C-FAR Food Safety Strategic Research Initiative Table 1, Project 2). Tylosin is one of the most often-used antibiotics used for growth-enhancement in pork farming. Using a high performance liquid chromatographic method, rapid reductions in the measurable Tylosin added to the aerobic thermophilic reactor were demonstrated within 24 hours. Approximately 90% reductions were seen at subsequent times. Additional tests with autoclaved swine manure with sodium azide added to attempt to eliminate cell viability and

[2] F. E. Dische and S.D. Elek. 1957. Experimental food poisoning by Clostridium Welchii. Lancet. 2:71.

metabolism showed nearly equivalent reductions to those with viable swine manure biomass. Exhaustive extractions were done to eliminate the possibility of removal by reversible sorption processes. We do not know yet whether Tylosin has been converted chemically or enzymatically to other forms of carbon or if it remains irreversibly sorbed, but as an intact antibiotic molecule.

Table 6. Initial counts of fecal bacteria and counts after six days of aeration, mixing and heat. Geometric mean concentrations are expressed as CFU/ml with 2 standard errors in parentheses. Samples where bacteria were not detected were set at 1 CFU/ml for statistical purposes.

	Time in 3-liter Reactor (n=3)		Time in 1000-gallon reactor (n=2)	
Bacteria	0 days	6 days	0 days	6 days
Campylobacter jejuni	25,118 (4.4)	ND*	13.5 (182)	ND
Salmonella Enteriditis	134,896 (1.85)	ND	ND	ND
Escherichia coli	398,107 (20.4)	ND	2,880,031 (69.2)	ND
Stapholococcus aureus	52,481 (1.8)	ND	26.3 (708)	ND
Enterococci	1,258,925 (19.5)	8.8 (204)	3,311,311 (7.7)	10.5 (12)
Clostridium perfringens	4,073,802 (3.7)	513 (118)	4,168,694 (6.9)	12.6 (162)

* ND = below detection limit

We have also tested the removal of Tylosin at low concentrations through collaboration with Mike Meyers of USGS. This has indicated similar Tylosin's behavior at concentrations of interest in swine manure. Ellen Storment of the Ill. Dept. of Agr. Animal Disease Lab at Centralia has performed an antibiotic resistance and availability bacterial bioassay to determine if antibiotic availability remains after aerobic thermophilic treatment. None of the reactor product after the Tylosin removal showed inhibition to growth of a sensitive test bacterial strain.

The significance of these works are that: 1) an organic food fertilizer product would have considerably lower pathogen content than that expected from manure composting and would have much lower detectible Tylosin content, 2) we are building a case to suggest that aerobic thermophilic treatment may lead to lower risk for forming antibiotic-resistant pathogens (because of lower antibiotic levels) and has the ability to thermally-inactivate most of those that may form in manure production, storage and application. These results may impinge on the "antibiotic-resistant pathogen" problem emerging as a concern for the pork-producer.

We have concluded runs for the popular antibiotics chlortetracycline and oxytetracycline and are in the process of interpreting results.

VALUE-ADDED PRODUCT

For this process to show positive economics, the heat produced must be used productively year-around. It is straightforward to use the heat in buildings for warmth in the cold months, but this alone will not necessarily lead to short payout times for the process (of say 5 years or less). To try and solve this economic problem we investigated the design and costing of several options to use the heat in the warm months (Table 1, Project 3). The leading technical and economic choice was to thicken and dry the solids after reaction, using the heat of reaction to dry the solid product, and then sell the solids for use as a value-added fertilizer or a fuel for co-firing utility boilers. In one project (Table 1, Project 2), we collaborated with Dr. Alan Walters of the SIUC Plant and Soil Science Department and made nearly 200 lbs of dry fertilizer product for application to five vegetables over 2 growing seasons. Results from this project are still pending, but early indications are that as a fertilizer, the dry product is equivalent to a standard fertilizer mix. Virtually no *E. coli* were found in the vegetables. Another bacteria found in the vegetables did not likely arise from the dry fertilizer product as its source, but from other standard farm sources.

FULL-SCALE DEMONSTRATION

In 2002, the Illinois Attorney General's Office selected our proposal to build a full-scale aerobic thermophilic swine manure treatment system at an Illinois pork producer's facility to demonstrate odor reduction (Table 1, Project 5). We have selected the producer, have characterized the waste for treatment and are proceeding on system detailed design. We hope to go out for construction bids soon. This project has truly enabled the vision of C-Far SRIs to bring technology to the Illinois producer.

CONCLUSIONS

- Three experimental systems were constructed and operated to test and validate process efficacy. These were 1) a 2 L Laboratory Biocalorimeter, 2) a 1000 gal Batch Pilot Plant System, and 3) a 1000 gal Semi-continuous Pilot Plant System.

- Heat production from the aerobic thermophilic process was measured in the Lab system and verified in both Pilot Systems. Biological heat production is related to COD removals.

- Air recycle used to increase the amount of recoverable heat from the system was shown not to affect heat production in a negative way.

- Odor removal was noticed at the lab scale and verified by Olfactometry and GC-MS analysis at the Batch Pilot Plant Scale. It is reasonable to expect over 80% odor removal from a full-scale semi-continuous system after system startup.

- Nitrogen in the system is converted to ammonia. The most current system configuration includes a scrubber system to eventually convert the ammonia to nitrogen gas.

- Both types of pilot runs indicate P is removed from the liquid reactor product. The most likely hypothesis is that P is converted to an insoluble inorganic compound which may collect at the bottom of the reactor. The fate of this type of P upon land application was not conclusively determined.

- The process effectively lowers the levels of zoonotic pathogens. Two pathogens survived the reactor conditions at greatly reduced levels.

- The antibiotic Tylosin is removed as measured by LC and LC-MS analytical methods at concentrations relevant. The resulting reactor solids fail to inhibit the growth of a sensitive bacterial strain, thus removing antibiotic activity. This may factor into current discussion that pork farms using antibiotics may cause increased levels of antibiotic-resistant pathogens. Results from chlortetracycline and oxytetracycline are pending.

- A dry value-added product may be made with the reactor heat and reactor product, leading to an economical year-around process. Evaluation of this product as a vegetable fertilizer is underway.

- Including the components to manufacture and sell the value-added dry product, this technology is expected to pay off its initial investment in 5 years or less. This might be compared to the 8-10 years required to pay off anaerobic digestion systems.

- Detailed designs for a full-scale system to be built on an Illinois farm are in preparation.

- Technically and economically, this odor-removal technology compares favorably with other manure management technologies and should be given strong consideration.

Reducing Dust and Gas Emissions using an Aerodynamic Deduster

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ABSTRACT

Dust and ammonia are two major air pollutants that are emitted from confinement animal feeding operations (CAFO) as well as odor. Many air-cleaning technologies are available, but most of them are not applicable for CAFO pollutant control not only because they are out of typical CAFO owners' budget, but also because few of them are able to reduce the emission of these three pollutants simultaneously. There is a need for a cost effective device that can reduce simultaneously dust, ammonia and odor. The diffusion-coagulation-separation (DCS) system was developed based on this need. Performances of two prototypes are summarized in this paper followed by an update of the latest field evaluation of a vertical prototype of simpler structure. Comparison between the performances of two field-scale prototypes was provided for future system optimization. The vertical prototype contains fewer concentric multi-annual dedusters, which decreased slightly the dust removal efficiency. On the other hand, the gas removal efficiency increased significantly due to the longer residence time for gas removal. What is more, the vertical DCS is simple in structure and cost less in manufacture and operation. The design of next generation DCS system was recommended based on the field evaluations of these two pilot scale prototypes. A vertical setup is recommended in favor of long residence time, little space requirement, and higher stack for faster emission dilution. In addition, more nozzles at the lower stage and longer separation section are recommended. The next generation DCS, prototype #3, is expected to have higher efficiency for both dusty and gaseous pollutants without increasing too much cost.

Keywords: Dust emission, ammonia emission, air cleaning, diffusion-coagulation-separation (DCS) system, and deduster

INTRODUCTION

Dust and toxic gases emitted from confinement animal feeding operations (CAFO) have been major concerns to the public, scientists, and government agencies. Primary health problems are associated with CAFO indoor environments stem from a complex mixture of hazardous airborne dust particles carrying ammonia, bacteria, and odor. Possibilities for control of dust emission have been extensively reviewed (Carpenter 1986, Dawson 1990, Zhang 1999, Tan and Zhang 2002). Common strategies for dust control include source control, ventilation, and dust separating from the air stream with air cleaning devices including cyclones, filtrations, wet scrubbers, electrostatic precipitators (ESPs), and so on. However, devices that are applicable for CAFO dust control are limited due to the special property of CAFO indoor air and the limitation in most owners' budget. Therefore, a facility that can simultaneously reduce the emission of dust and ammonia is desired.

Advances in air cleaning technologies have made a cost-effective device possible for CAFO emission control by combining the following technologies. An aerodynamic deduster as shown in Figure 1 was developed by Christianson et al. (1999). Laboratory test results showed that this uni-flow aerodynamic deduster could efficiently separate the particle at a cut size of 1 or 4.5 μm, depending on the particle sizing instruments, and the dust collection efficiency based on mass was over 85% at a pressure drop of about 150 Pa. Although only dry particles were tested in lab, the deduster was anticipated to be able to separate other particulate matters including CAFO dusts and liquid droplets from air stream, because it operated at a non-contact format. In addition, wet scrubbers have been proved able to remove gaseous pollutants. Therefore, it is possible to remove part of the odorous gases while removing dusts by combining the wet scrubber with the aerodynamic deduster, because gaseous and fine particles can be captured by large particulates such as water droplets by taking advantage of the diffusion of gas molecules and small particles and the coagulation among particles in various sizes.

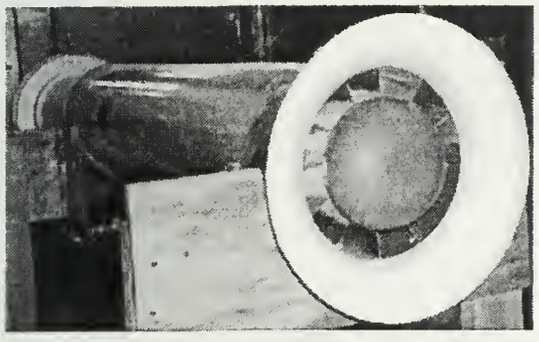

Figure 1. Aerodynamic deduster

A diffusion-coagulation-separation (DCS) system is developed based on the principle described above. It combines the technologies of aerodynamic deduster and wet scrubber. Before this paper, two prototypes, laboratory scale- and field scale- prototypes, have been developed and tested in lab and field, respectively. The corresponding design and test results have been reported elsewhere (Zhang et al. 2002), and a summary is provided as following

LABORATORY SCALE PROTOTYPE

The laboratory scale prototype was developed base on the 288 cfm uniflow aerodynamic deduster. The prototype was built by attaching a wet-scrubber (diffusion-coagulation section) in the front of the deduster (see Figure 2). The wet scrubber was a metal elbow acting as a hood. The laboratory test results showed that the prototype diffusion-coagulation-separation air cleaner (DCS) could effectively remove both dust and ammonia from an air stream. The overall dust removal efficiency was 85% and 57% ammonia removal was observed at the combination of 60% power with 10 ppm NH_3 concentration.

Figure 2. A bench scale prototype diffusion-coagulation-separation air cleaner (DCS)

FIELD-SCALE PROTOTYPE #1

Based on the 288 cfm bench scale prototype, a 4,000 cfm pilot scale prototype #1 was designed and fabricated. As shown in **Figure 3**, prototype #1 contained three concentric annual dedusters. The outer cylinder of a smaller deduster serves as the inner cylinder of a bigger one. Therefore, the total air delivery is increased without increasing the overall volume of the unit. The diameter of the exhaust fan is 21″.

Figure 3. Schematic of the 4,000 cfm deduster

The water reclamation efficiency test showed that about 90% water could be collected by the catch basin and water collection box. The water loss was less than 10%. The air flow rates of the DCS at different power levels are shown in Figure 4. The air flow rate decreases as the static pressure increases.

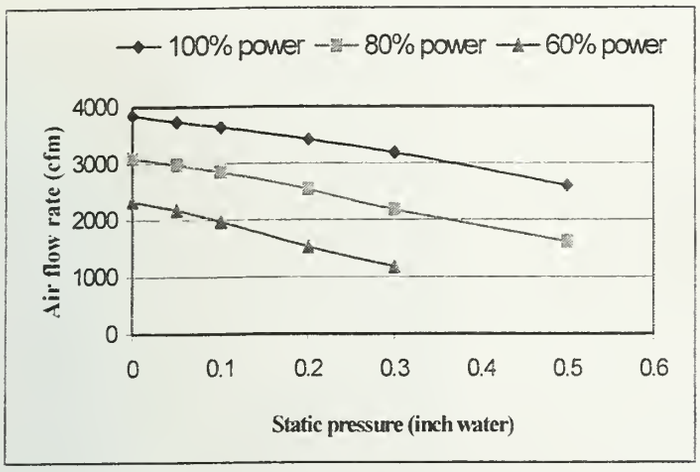

Figure 4. The air flow rate of the DCS at different power level

Field evaluation results showed that the dust mass removal efficiency was 91% at 60% power and 89% at 100% power respectively. There was a reduction in NH_3 observed at different power level. The ammonia removal efficiency was about 25%. Due to the low NH_3 field concentration in summer, it was difficult to evaluate the ammonia removal efficiency. It is worthy to note that the total dust mass removal efficiency was higher than a deduster without a wet scrubber section, because particle reentrance was greatly reduced.

The preliminary results indicated that the longer the retention time is, the higher the gas removal efficiency. However, the residence time was limited by the horizontal setup. A vertical DCS is recommended in order to attain longer residence time. In addition, four sets of concentric dedusters made the system complex and expensive in construction and maintenance. A DCS with fewer vanes is expected for the consideration of investment. This paper summarizes and updates the development of DCS system as a cost effective device for emission reduction of dust and toxic gases from CAFO.

VERTICAL PROTOTYPE

Based on previous studies, another vertical field scale prototype (prototype #2) was developed. The total height of this prototype is about 15 ft (4.5 m). The outer tube is 30" in diameter. As shown in Figure 5, it contains four parts connected via flanges: an elbow, diffusion and coagulation section, separation section, and an exhaust fan. To differentiate it from its predecessor, this prototype is termed vertical prototype, because it was mounted vertically with fewer space requirement. For comparison purpose, the exhausting fan that was also used in horizontal prototype was used in the vertical prototype to maintain a 4,000 *cfm* capacity. A variable frequency controller was connected to the fan to adjust the power and speed of the fan.

Figure 5. Schematic of the vertical prototype.

The main purpose of this prototype was trying to achieve same even better performance with simpler structure. Instead of three sets of dedusters as in the horizontal deduster, the vertical one is composed of two concentric annual dedusters. The outer cylinder of a smaller deduster serves as the inner cylinder of a bigger one. Therefore, the total air delivery could be increased without increasing the overall volume of the unit. The polluted air enters the system via the elbow, which changes the airflow direction from horizontal to vertical. Diffusion and coagulation section was made of plastic, inside which are only three BETE PJ40 nozzle installed at different elevation along the centerline of the tubes. Mist was generated by these nozzles when water was supplied. Gas molecules and fine particles diffuse to liquid mists, and small particles coagulate with (attract to) each other to form larger particulates. The amount of nozzles in the vertical prototype is much less than that in the horizontal one. It was expected to reduce significantly the water consumption by reducing nozzle amount. Large particles and droplets are separated from the air stream when the mixture enters the separation section. Instead of 3 sets of vanes in prototype #1, there are only two sets of vanes in prototype #2, which reduced much labor and cost in manufacture. The vanes are manufactured by *Bob's* machines shop, and they were glued on the tubes. Two sets of vanes, big vanes and small vanes, are employed in the collection zone. Big vanes are located between the outer tube and the mid-tube, and the small vanes are located between the mid-tube and the inner tube.

FIELD EVALUATION

The DCS system was mounted on the sidewall of a swine building at Moorman swine research farm. Spray water was supplied by the onsite water line without pressure control, trying to operate as close to real situation as possible.

Dust removal efficiency measurement

The inlet and outlet dust concentrations were measured using two identical dust collection systems, which are similar to that developed by Wang et al. (1999). Each system contains three glass fiber filters, three filter holders, three critical venturi, an electrical air pump, and some plastic tubing. The pore size of the filters is 0.8 μm. Filters were 37 mm (in diameter) filter holders. Both the filters and their holders are from *Millipore Aerosol Analysis Monitor, Inc.* Critical venturi connected to downstream of the filters and the pump was used to keep the constant air flow rate of 20 *l/s* for each filter.

Both dust collection systems were calibrated in BESS lab before they were put in field, one for inlet and the other for the outlet of the vertical deduster. The system for inlet was placed inside the building to measure dust mass concentration, and the one for outlet was placed on a frame above the exhaust fan. The filter surfaces were kept perpendicular to air flow. After both systems running simultaneously for 24 hours, the filters were dried in TCC laboratory and weights recorded. The weight collected at inlet or outlet of DCS was obtained by averaging the dry dust weights on three filters in corresponding dust collection system. Then the dust removal efficiency of prototype #2 was calculated using the following equation.

$$\eta_{dust} = \left(1 - \frac{Average\ outlet\ dust\ mass}{Average\ inlet\ dust\ mass}\right) \times 100\% \qquad [1]$$

Ammonia removal efficiency measurement

Ammonia concentration was measured manually using colorimetric gas detector tubes for ammonia with an aspirating pump. The ammonia detector tubes are Precision Gas Detector Tubes Nos. 105SC, 120SD, and182U from Matheson-Kitagawa, Inc, N.J. Their range is 0.2-20 ppm with a detectable limit of 0.1 ppm. The scale of the detector is marked as 1, 2, 4, 6, 8, ... , 20 in ppm.. The aspirating pump is 1 pump stroke also from Matheson-Kitagawa, Inc, N.J.

The inlet and outlet ammonia concentrations were measured to estimate the gas removal efficiency of prototype #2. Preliminary tests showed that the gas concentration at either inlet or outlet was not uniformly distributed, several sampling points were selected and the average concentrations were used for calculating the ammonia removal efficiency.

$$\eta_{NH_3} = \left(1 - \frac{Average\ outlet\ NH_3\ concentration}{Average\ inlet\ NH_3\ concentration}\right) \times 100\% \qquad [2]$$

Since a gas detector tube can only be used once, only five or six of the representative points (see Figure 6) at each surface were sampled considering that the ammonia detector tubes are relatively costly.

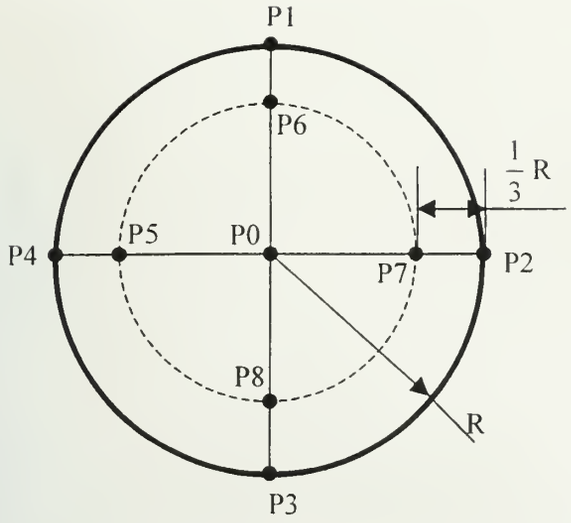

Figure 6. Potential ammonia concentration sampling points on the imaginary surfaces of inlet and outlet.

RESULTS AND DISCUSSION

The dust removal efficiencies at different fan power levels are shown in Figure 7. The dust removal efficiency was about 71%, 77%, and 75 % when the fan operated at 60%, 80%, and 100% of its full power, respectively. Since these data were obtained under different operation conditions such as different humidity, temperatures, and wind speeds, it is temporarily concluded that the overall dust removal efficiency of the DCS falls in the range of 70%-80%. It also indicated that the fan power level had slight influences on the dust removal efficiency; this confirmed the similar results obtained from prototype #1, where dust removal efficiency changed from 91% to 89 % when fan power varied from 60% to 100%.

Note that the sampling location inside the building is 3 ft away from the inlet surface, where the air velocity is much lower than that at the DCS inlet surface. According to Bernoulli equation,

$$P + \frac{1}{2}\rho v^2 + \rho g h = \text{constant} \qquad [3]$$

air was compressed while flowing towards the inlet surface of the DCS system. Therefore, the dust concentration sampled should be lower than that entering the DCS system, which means that the overall dust collection efficiency might be less estimated and the real dust removal efficiency could be higher than 80%. Further quantitative investigation is needed for testing conclusion.

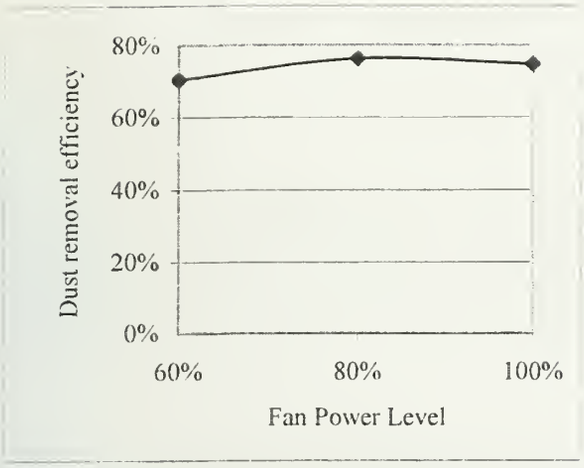

Figure 7. Dust removal efficiency vs. fan power level.

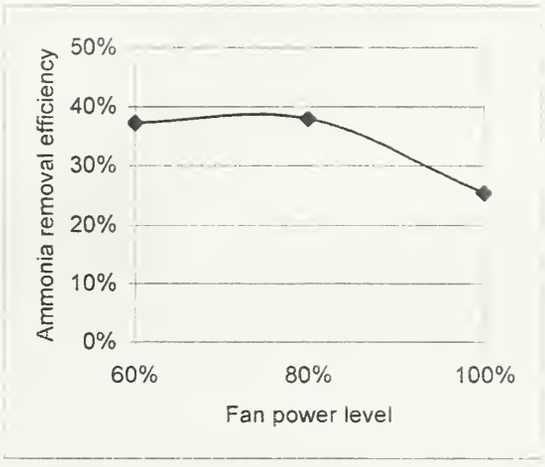

Figure 8. NH_3 removal efficiency vs. fan power level.

Ammonia removal efficiencies at different fan power levels are shown in Figure 8. The data were obtained from the same tests, and there were no obvious changes in operation conditions. The highest ammonia removal efficiency of 38 % was obtained at the 80% fan power level. The efficiency was barely the same at 60% and 80% power levels, but that was much lower at 100% power level. The overall trend indicated the relationship between the gas removal efficiency with residence time.

There was only one nozzle at each stage, and spray was not able to cover all the cross section of the outer tube. As illustrated in Figure 9, the outer tube of the DCS is 30", but the coverage of a single nozzle spray was only 24" in diameter. There was a large fraction of the pollutants that could not be captured by the droplets at first time. The gas removal efficiency could have been higher if more nozzles had been installed on the same level.

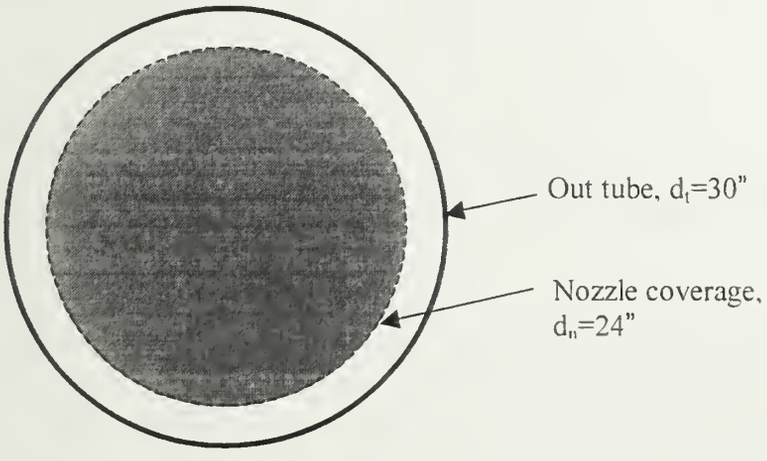

Figure 9. Schematic of the spray coverage problem

Ammonia concentration was less than 4 ppm due to the limited amount of pigs in the swine building, and the high ventilation rate in the early summer. The ammonia removal efficiency could be higher if more pigs had been housed or in winter, when ammonia concentration is usually higher.

By the way, maldistribution of ammonia distribution at the inlet surface was observed. Awareness should be taken in future measurements. Table 1 summarizes the ammonia concentrations (in ppm) at different sampling points. The average values are illustrated in Figure 10. Higher concentration was found at the bottom edge of the inlet surface than other points.

Table 1. Ammonia concentration maldistribution at the DCS inlet (ppm)

Fan Power	P0	P1	P2	P3	P4	P5	P6	P7	P8
60 %	2.8	2.0	3.0	3.4	-	-	-	2.5	2.1
80 %	2.5	2.2	2.5	3.9	-	-	2.0	-	2.0
100 %	2.1	-	-	3.8	1.2	1.5	-	-	2.1
Average	**2.5**	**2.1**	**2.8**	**3.7**	**1.2**	**1.5**	**2.0**	**2.5**	**2.1**

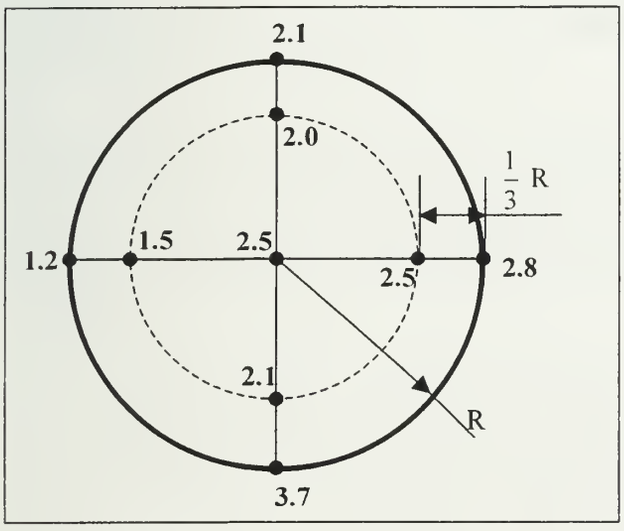

Figure 10. Ammonia concentration maldistribution at the DCS inlet (in ppm)

Although the bench scale prototype showed uniform distribution of outlet ammonia concentrations, it was not so for prototype #2. This might be due to the apparent different sizes between the fans, the different air flow patterns, and the different supplied powers. There was certain ammonia concentration maldistribution at the outlet, but not so obvious as that at inlet.

The simple structure, few spatial requirement, and low cost of the new generation were achieved at the price of lower overall performance of the vertical DCS. On one hand, the long residence

time increased over efficiency, but on the other hand, the air pollutant removal efficiencies were lower than the horizontal one due to the following over-simplified designs.

In the diffusion and coagulation section, turbulent flow is expected, while high turbulence intensity in separation section will reduce the droplet separation efficiency. Since there were only two sets of vanes in the separation section, the gaps of each concentric deduster were wider, which would increase the turbulence intensity and decrease the particle separation efficiency. This might also explain why some droplets were not separated from the air stream but were observed at the exit of the DCS system.

SUMMARY AND RECOMMENDATIONS

Up to date, one bench scale and two pilot scale prototypes, #1 and #2, were designed and evaluated. There was one deduster, three concentric annual dedusters, and two concentric annual dedusters in the bench scale prototype, pilot scale prototype #1 (the horizontal prototype), and pilot scale prototype #2 (the vertical prototype), respectively.

The experimental evaluation results provided valuable data for future optimum DCS system design. All the test results indicated that the longer the gas residence time, the higher ammonia removal efficiency. However, dust removal efficiency was not significantly affected by the residence time (*i.e.*, fan power levels), and the amount of concentric dedusters did not influence the dust removal efficiency.

The pilot scale prototype #1 was complex in structure and cost much to manufacture. The advantage of it is that high dust removal efficiency (90%) was achieved due to more concentric annual dedusters with longer separation section. On the other hand, the ammonia removal efficiency was very low (25%) due to short gas residence time, which is limited by its horizontal orientation.

The pilot scale prototype #2 was designed and installed vertically for more gas residence time. At the same time, the structure was much simpler than its predecessor was. The amount of concentric annual dedusters was reduced half, and the separation section time was shorter thean that in prototype #1. The overall performance was better than that of prototype #1. The dust removal is dropped slightly from 90% to 80%, but the ammonia removal efficiency increased significantly from 25% to 38%, which could be even higher if more nozzles had been installed.

Based on the field evaluations of these two pilot scale prototypes, a vertical setup is recommended for next generation DCS system in favor of long residence time, little space requirement, and higher stack for faster emission dilution. In addition, more nozzles at the lower stage and longer separation section are recommended. The next generation DCS, prototype #3, is expected to have higher pollutant removal efficiency for both dusty and gaseous pollutants without increasing much cost.

Data in winter with more pigs housed are needed, and the following are recommended for future DCS evaluation.

1. Take samples on days that wind speed is low.

2. Use more accurate ammonia tube for ammonia concentration measurement.
3. Take sample as close to inlet surface as possible.

ACKNOWLEDGEMENT

Funding by the Illinois Council on Food and Agricultural Research (CFAR) is gratefully acknowledged.

REFERENCES

BESS, 2002. (There is a paper describes the fan test chamber by Christianson et al.)

Carpenter, G.A. 1986. Dust in livestock buildings—review of some aspects. *Journal of Agricultural Engineering Research.* 33:227-241.

Christianson, L L., Zhang, Yuanhui, Wang, Xinlei, Riskowski, G. L., and Ford, S. E. Particle separation efficiency of a uniflow deduster with different types of dusts, *ASHRAE Transactions*. 107 (2):93-98, 2001.

Dawson, J. R., 1990. Minimizing dust in livestock buildings—A review of possible alternatives, to mechanical separation. Journal of Agricultural Engineering Research. 47:235-248.

Zhang, Y. 1999. Engineering control of dust for animal facilities. *Proceedings of international symposium on "dust control for animal production facilities"*. Aarhus, Denmark, May 30-June 2, 1999. pp 6-11.

Zhang, Y., X. Wang, G.L. Riskowski, L.L. Christianson, S.E. Ford. 1999. Particle Separation Efficiency of a Uniflow Deduster with Different Types of Dusts. *ASHRAE Transactions*.

Tan, Z. C. and Y. Zhang. 2002. An Overview of Particulate Matters in Indoor Environments: Sources, Effect, and Control, ASHRAE Transactions (Submitted for review)

Wang, X., Y. Zhang, L. Zhao, G.L. Riskowski. 1999. Development of a Multi-Point Aerosol Sampler Using Critical Flow Control Devices. *ASHRAE Transactions* 105(2).

Zhang, Y. Ni, J.B., and Z. C. Tan, *Various capacity aerodynamic dedusters: Development and evaluation of large concentric diffusion-coagulation-separation (DCS) systems in swine buildings*. Unpublished Project Progress Reports C-FAR Project # IDA CF 99SI-63-3A AE. May, 2002

A Synthetic Earthen Lagoon Cover to Reduce Odor Emission

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ABSTRACT

One of the significant odor sources on swine farms is manure storage. This study investigated reducing odor and gas emissions from a 29 m by 39 m anaerobic swine lagoon by capturing gases beneath a 0.41mm thick, flexible reinforced polyethylene membrane. The cover was anchored and sealed about its perimeter by burying the edges in a trench around the lagoon embankment. A fan installed alongside the lagoon drew gases continuously from a looped perimeter duct system to provide a (suction) pressure differential of approximately 500 Pa to hold the lagoon cover in place. The measured average emission rates of CO_2, H_2S, NH_3, and CH_4 were approximately 270 kg/hectare-day, 92, 20, and 940 g/hectare-day, respectively. The average flow rate from the suction fan was 0.194 m^3/s (411 cfm) and average odor intensity was 598 OU/m^3. The derived odor emission rate was 116 OU/s. The total cost of the lagoon cover was \$7,800 or \$3.75/m^2 (\$0.36 /ft^2). Operating cost was approximately \$36/month, based on an electrical rate of \$0.10 per kWh.

Keywords: Anaerobic lagoon, odor control, manure lagoon covers

Odorous gases are produced from a number of sites around livestock facilities, including fan exhausts from the barn, emissions from manure lagoons, and land applications of manure. One of the major sources of odor is liquid manure stored in open earthen or concrete structures. Anaerobic lagoons provide a popular, low cost means of manure storage and treatment, and with proper design and management, they can be effective in reducing the intensity of odor release. However, during late spring when ambient temperatures and day length increase, odors from lagoons often become temporarily much more intense (Safley et al.1993) and can pose a problem to the surrounding community. Covering the structure to capture gases can control odor emissions year-around from lagoons.

Different types of lagoon covers are available. Floating covers made of sheets of flexible synthetic materials are often difficult to maintain because of the wind and fluctuations in the manure levels during the year. Floating, permeable materials such as low-density clay balls or chopped crop residues are also used as covers but these materials can sink in the manure, form clumps, and/or plug the pumping equipment. Floating permeable covers are also affected by weather and especially by high winds, and in the case of crop residues such as straw ("biocovers"), the covers may need to be replaced every year or more often (MWPS 2002).

Therefore, a more economical and more effective covering method for manure lagoons is desirable.

A previous study at the University of Illinois investigated an air-supported structure as a cover for a swine lagoon (Funk et al. 2002). While that cover was inexpensive to install, the cover offered some difficulties of maintenance and experienced a failure of a fabric seam, which ultimately led to the cover being removed and discarded.

OBJECTIVES

For the current study, an impermeable, synthetic floating cover with a suction fan system was selected. Objectives were:

To develop and install a cost effective odor control technology for manure storage;

To measure gas (hydrogen sulfide and ammonia) leakage rates and odor emission into the surrounding atmosphere;

To measure and evaluate biogas (carbon dioxide and methane) concentrations.

MATERIALS AND PROCEDURE

A commercial lagoon cover (Figure 1) marketed by Encon Technologies, Inc. was installed on one of the primary anaerobic lagoons at the 560-sow farrow-to-finish University of Illinois Moorman Swine Farm. The lagoon measured 37 m by 49 m (120 ft. by 160 ft.) at the top of the lagoon embankment, and 29 m by 39 m (96 ft. by 128 ft.) at the top surface of the lagoon liquid. Lagoon loading rate was approximately 0.09 kg VS/m^3-day (5.8 lb VS/ft^3-day). The cover consisted of a 0.41 mm thick, black, mesh-reinforced polyethylene liner floating on top of the lagoon liquid; the membrane was sealed around its perimeter by burying the cover's edge in a trench dug into the lagoon embankment and backfilling with soil. A looped air duct consisting of 10-cm (4-inch) inside diameter corrugated, perforated polyethylene field tile was placed around the perimeter of the lagoon at the top of the embankment and beneath the cover. A centrifugal fan (Dayton Electric Model QBR137F) drew out a small amount of air from under the cover to create the negative pressure, keeping the cover down tight onto the lagoon surface and protecting the flexible membrane from wind damage.

MEASUREMENT PROCEDURES

All measurements and gas samples were taken at the duct entering the fan (Figure 2). The temperature and relative humidity of the gas being drawn off the lagoon by the fan were measured using a thermo-hygrometer (Model 900, General Eastern, Woburn, MA). The temperature and relative humidity sensors had published accuracies of ± 0.3 °C and ± 2% RH, respectively.

The pressure drop across the exhaust fan was measured using a digital manometer (Series 475 Mark III, Michigan City, IN) with a pressure range of 0 to 995 Pa (0 to 4 in. water column) with a manufacturer's estimate of accuracy of 0.6% of full scale.

EMISSIONS

NH_3, H_2S, and carbon dioxide (CO_2) concentrations in the downstream of the exhaust fan and the ambient air were measured using colorimetric detector tubes. Specifications of the detector tubes are shown in Table 1. A 100 ml per stroke gas sampling pump (Model 8014KA, Matheson Safety Products, Rutherford, NJ) was used to draw air through the different types of colorimetric detection tubes directly from each sampling port. Sampling was performed weekly, on the same weekday each time.

The average monthly concentrations of gases were calculated from the weekly measurements. From the gas concentrations and airflow rate, the emission rates were calculated using:

$$\mu = Q * C * \rho \qquad (1)$$

where

μ= Emission rate, kg/day

Q= Air flow rate, m^3/day

C = Concentration of gases, m^3 of gas per m^3 of air

ρ= Density of the individual compound of concern, kg/m^3

Biogas quantitative analysis was performed using an ambient air analyzer (205A Series MIRAN Sapphire®, The Foxboro Company, Foxboro, MA) to measure the methane concentrations from the lagoon gas under the cover. The analyzer consisted of a single-beam infrared spectrophotometer and had a sample flow rate of 15 L/min. The instrument's published accuracy for methane measurement was ± 15% of full scale.

Air samples for dilution-to-threshold olfactometry were taken with a SKC Vac-U-Chamber, 10-L Tedlar air sampling bags with either a single stainless steel fitting or polypropylene fitting, and a Buck I.H. Pump. Bags were purged prior to drawing samples. Samples were diluted with filtered air and presented to panelists in an olfactometry laboratory. The odor dilution-to-threshold values are reported as odor units per cubic meter of exhaust air (OU/m^3) since the exhaust fan was a point source whose total airflow rate is measured. Over a nine-month period, gas samples were collected once per month, drawing three bag samples consecutively at each time.

A GC/FID was used to measure the concentration of total volatile organic compounds (VOC) and sulfur compounds in the air drawn from beneath the lagoon cover. The gases were captured using a VOC trap (Tekmar Stell Trap), which consisted of a 0.3 cm diameter, 30.5 cm long stainless steel tube with adsorbent material (OV-1/Tenax/Silica Gel) able to trap VOC and sulfur compounds. During sampling, the trap was connected to a vacuum pump that ran for a specified low flow rate (approx. 20 ml/min) for a length of time sufficient to draw a volume of approximately 0.25 L through the trap.

The VOC collection apparatus included a 0.3 cm diameter tube of Teflon running from the sampling location to the VOC trap. Total VOC, the sum of the areas under the peaks in the GC graph, was reported. Calibration with standard gas(es) to determine absolute VOC concentration was not performed in this study.

Experiments were conducted from August 2001 to April 2002.

RESULTS AND DISCUSSION

Mechanical

The cover did not experience any significant failures during the period of the study. The membrane material tended to collect gas bubbles (Figure 1) but the bubbles did not present any operational or structural problems.

Gas Emissions

Table 2 shows the average monthly concentration of gases and the emission rates of gases calculated from Equation 1. The average static pressure of the lagoon exhaust fan for the entire measurement period was 563.5 Pa (2.27-in. water).

The measured average emission rates of CO_2, H_2S, NH_3, and CH_4 were approximately 63 kg/d, 19, 4.3, and 200 g/d, respectively. The measured NH_3 was about 1/3, and the H_2S was 45% of that emitted from the inflatable cover previously studied by Hussey (2000) on the same swine lagoon. On the basis of the total lagoon area (Table 3), the emission rates with the floating cover were 270 kg/ha-d CO_2, 92 g/ha-d H_2S, 20 g/ha-d NH_3 and 940 g/ha-d CH_4. The ammonia emission was much less than, for example, the rates of 13,000-220,000 g/ha-d measured from a farrow-to-finish primary lagoon in Missouri by Zahn et al. (2002).Statistical analysis showed no significant relation ($R^2 < 0.2$) between temperature and CO_2, H_2S and NH_3 emissions. Much of the gas entering the duct came from the soil, and gas emissions from the lagoon liquid were consistently low. There was also no significant correlation found between relative humidity and gas emissions ($R^2 < 0.22$) or between methane emissions and temperature.

Effect of Lagoon Cover on Odor Emission

Results showed that odor dilutions-to-threshold were high at the beginning of summer and fall. These times coincided with the history of odor complaints from the neighborhood. The highest odor dilution-to-threshold was approximately 1200 OU/m^3, which occurred in June; the lowest odor was 240 OU/m^3 in December.

The odor emission rate (OU/s) is calculated by multiplying the odor concentration (dilutions-to-threshold) by the airflow rate of the exhaust fan (Table 4). The average airflow rate was 0.194 m^3/s (411 cfm) and averaged odor intensity was 598 OU/m^3. The derived odor emission rate was 116 OU/s, which over the area of the lagoon would be approximately 0.06 $OU/s\text{-}m^2$. Compared to the mean odor emission range of 4.0 $OU/s\text{-}m^2$ on a geotextile-covered southwest

Minnesota swine finishing lagoon (Bicudo et al. 2002), the impermeable cover limited odor emission to about 1.5% of that of the geotextile cover.

There was no evidence that odor dilutions-to-threshold and total VOC emissions were related in this study. Table 4 shows that odor was often higher while VOC peaks were lower especially in June, September and October. On the other hand, total VOC peaks were higher while odor dilutions-to-thresholdwas lower during the winter time. For this study the GC/MS protocol did not include calibration of the VOC peaks to derive total concentrations of VOC.

Economic

The total cost of installation of the reinforced 0.41 mm polyethylene material cover, engineering, mobilization, install labor and supplies was $7,800 for the 37 m by 49 m (120 ft. by 160 ft.) treatment lagoon, or $4.30/m^2 ($0.41 /ft^2). Operating cost was approximately $36/month, based on an electrical rate of $0.10 per kWh. There was no maintenance cost during the experimental period. Expected life of the cover was ten years. The cost was less than that for the air-supported cover reported by Hussey (2000), used earlier on the same swine lagoon. The capital cost, including installation, for the air-supported cover was $10.03/m^2 ($0.93/ft^2).

CONCLUSION

The impermeable synthetic floating cover with a suction fan/duct system could be an inexpensive alternative compared with other covering technologies such as floating biocovers or permeable geosynthetic covers. Emissions of gases and odors were low compared to uncovered lagoons of the same size . There were no mechanical failures of the cover material or the fan/duct system during the experimental period.

ACKNOWLEDGEMENT

Funding by the Illinois Council on Food and Agricultural Research (CFAR) is gratefully acknowledged.

REFERENCES

Bicudo, J.R., C.J. Clanton, C.L.Tengman, D.R. Schmidth, W. Powers, and L.D. Jacobson. 2002. A two-year study of the effectiveness of geotextile covers to reduce odor and gas emissions from manure storages. ASAE Paper No. 024195. Presented at annual international meeting of ASAE. St. Joseph, Mich: ASAE.

Funk, T.L., R. Hussey, Y. Zhang, and M. Ellis. 2002. Synthetic covers for odor and emissions control from earthen embanked swine lagoons. Part I: Positive pressure lagoon cover. Applied Engineering in Agriculture (submitted.) ASAE, St. Joseph, MI.

Hussey, R. A. 2000. Development of an Air Supported Structure to Reduce Gas Emissions From an Earthen Lagoon. MS Thesis. At Urbana, Champaign , IL.: Univ. of Illinois. (Dissertation #: 3 0112 047257917).

MWPS. 2002. Outdoor air quality. Section 3, Manure Management Systems Series. MidWest Plan Service, Ames, IA.

Safley, L.M. Jr., C.D. Fulhage, R.L. Hunke and D.D. Jones. 1993. Lagoon management. PIH-62. Pork Industry Handbook, Purdue University Cooperative Extension Service, West Lafayette, IN.

Zahn, J.A., A.E. Tung, and B.A. Roberts. 2002. Continuous ammonia and hydrogen sulfide emission measurements over a period of four seasons from a central Missouri swine lagoon. ASAE Paper No. 024080. Presented at the 2002 ASAE Annual Meeting. St. Joseph, Mich.: ASAE.

Zhang, Y. and W. Gaakeer. 1998. An Inflatable Cover for a Concrete Manure Storage in a Swine Facility. Applied Engineering in Agriculture. 14(5): 557-561.

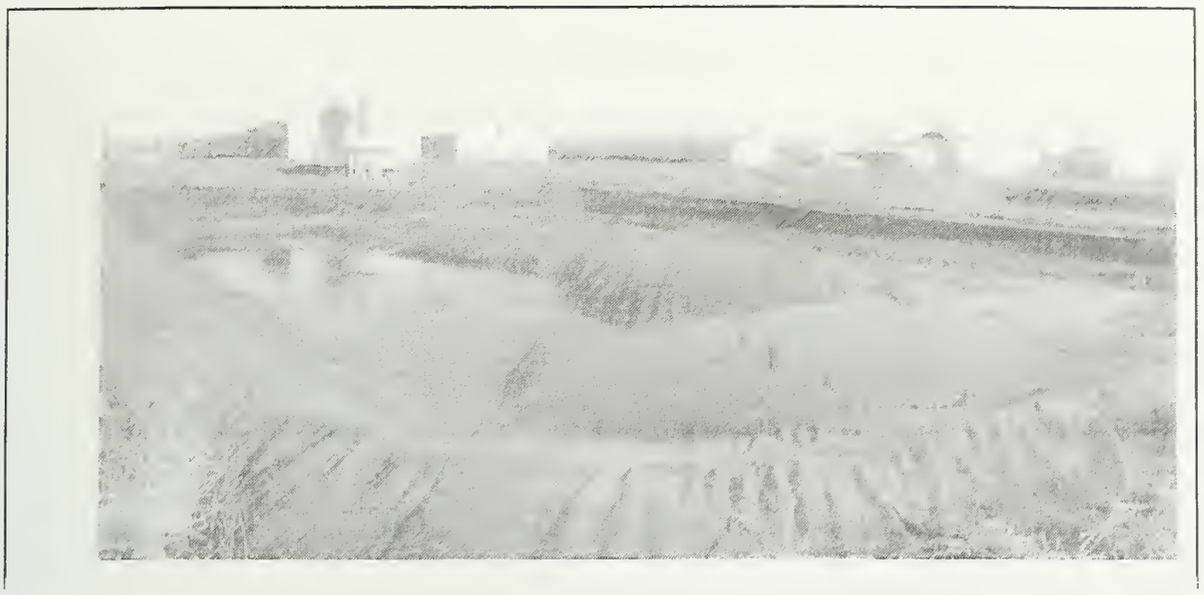

Figure 1. Negative pressure lagoon cover installed on anaerobic lagoon. Rainwater remains on top of cover. Biogas bubbles beneath the cover are eventually reduced by ventilation system. Manure originates from swine buildings in background.

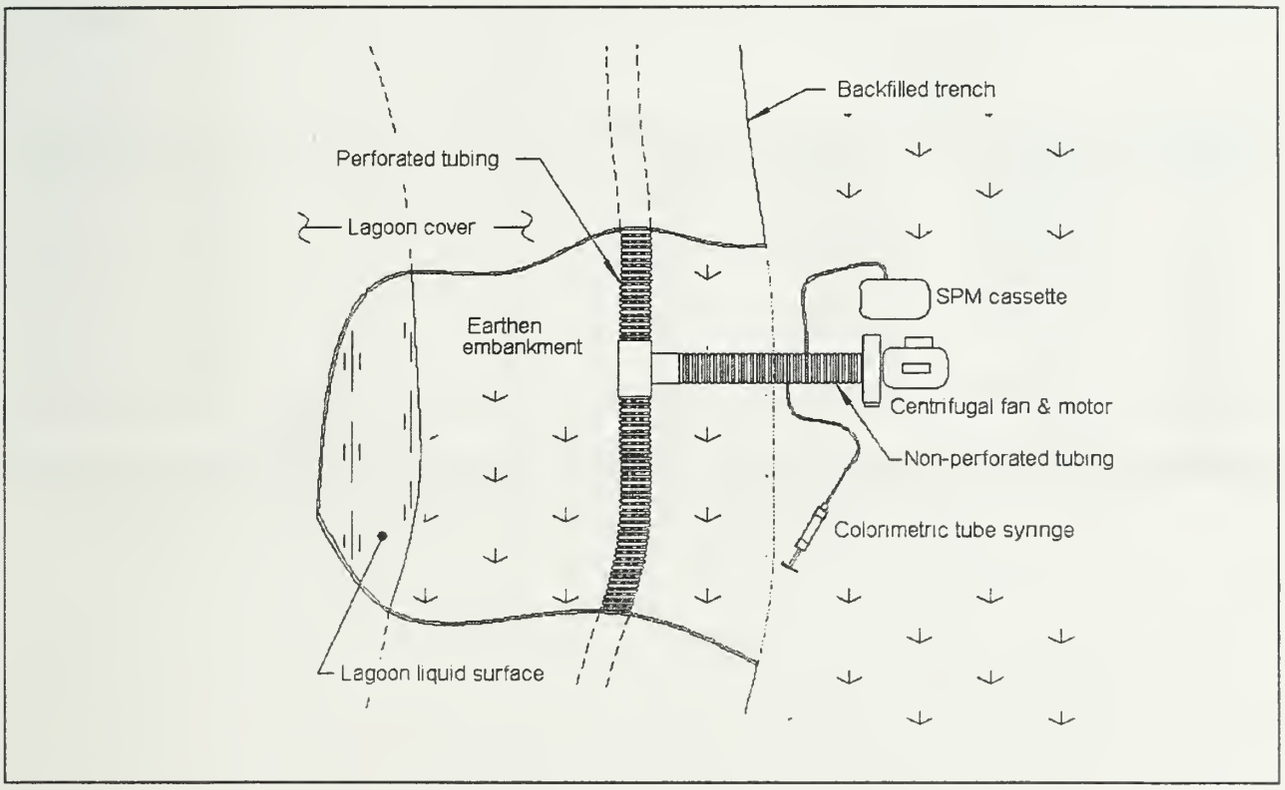

Figure 2. Fan and duct system that draws gases from beneath cover, showing small diameter Teflon sampling tubes, SPM gas sampling cassette, and colorimetric tube sampling syringe in place.

Table 1. Colorimetric tubes used for gas concentrations measured in gas samples taken from negative pressure lagoon cover. Tubes by Matheson Safety Products, Rutherford, NJ.

Gas measured	Tube No., Lot No.	Useful range	Manufacturer's published accuracy
Ammonia	105SD, 289038	0.2-20 ppm	+/- 10%
Hydrogen sulfide	102SD, 206019	0.2-6 ppm	+/- 10%
Carbon dioxide	8014-126B, Lot No. N/A	300-7000 ppm	+/- 10%

Table 2. Summary of CO_2, H_2S, NH_3, and CH_4 Measurements

	Air Flow	Air Temp.	Air Rel. Humidity	Concentrations Average (min-max) (ppm)			
Month	m^3/day	(°C)	(%)	CO_2[a]	H_2S[a]	NH_3[a]	CH_4[b]
Aug	16,400	39	46	3400	0.9(0.0-2.7)	0.8(0.0-3.0)	5.5
Sep	15,200	39	46	2600	0.8(0.1-4.0)	0.4(0.0-2.0)	4.4
Oct	15,500	25	76	2000	1.3(0.4-2.5)	0.1(0.0-0.5)	7.5
Nov	17,300	16	77	1500	1.2(0.0-4.5)	(0.3(0.0-2.5)	15.3
Dec	17,000	16	77	1300	1.0(0.0-5.0)	0.1(0.0-1.0)	22.0
Jan	17,000	12	72	1100	1.1(0.0-4.1)	0.1(0.0-0.6)	20.0
Feb	16,900	6	81	900	2.3(0.1-8.0)	0.0	21.0
Mar	17,600	6	57	1500	2.0(0.2-4.2)	0.0	21.0
Apr	16,500	17	74	4500	0.9(0.2-2.0)	0.2(0.0-0.5)	73.0
Average				2100	0.9	0.6	21.1
Standard Deviation (SD)				1100	0.4	0.4	19.5

[a] Average of all gas measurements for each month, colorimetric tubes and SPM.
[b] Average of methane measurements for each month, each measurement was conducted at noon time.

Table 3. Gas emission rates from covered lagoon.

	CO_2		CH_4		H_2S		NH_3	
Month	kg/d	kg/ha-d	g/d	g/ha-d	g/d	g/ha-d	g/d	g/ha-d
Aug	95	460	---	---	19	91	13.1	63
Sep	69	330	34	160	23	110	6.1	29
Oct	57	270	---	---	25	120	1.1	5
Nov	48	230	130	630	36	170	11.3	54
Dec	40	190	180	870	17	82	3.1	15
Jan	35	170	170	820	29	140	1.9	9
Feb	30	140	160	770	10	48	0.0	0
Mar	52	250	170	820	27	130	0.0	0
Apr	140	670	570	2700	5	24	6.0	29
Average	63	270	200	940	19	92	4.3	20

Table 4. Odor dilutions-to-threshold and VOC peaks in covered lagoon emissions.

Month	Odor dilutions-to-threshold and odor units (OU/m^3)	Total VOC peaks detected by GC/MS (x 100,000)
Jun	1200	7.8
Jul	660	13
Aug	420	8.2
Sep	990	8.3
Oct	870	3.4
Nov	510	6.8
Dec	240	5.5
Jan	510	30
Feb	570	----
Mar	21	0.23
Apr	1400	----

Manure Liquid-solid Separation Factors That Determine System Choice

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INTRODUCTION

Finishing pigs produce, at an average 150-pound bodyweight, about one pound of total manure solids per day, within the total manure volume of about 1.2 gallons per day (9.5 lb). Approximately 80 percent of the total solids are volatile solids and can be broken down further in a digester, anaerobic lagoon or similar treatment unit. In a pit under a building, finishing pig manure may have a concentration of about 50 lb/1000 gallons total N, 33 lb/1000 gallons ammonium-N, 42 lb/1000 gallons total P, and 30 lb/1000 gallons K (MWPS 2000). Very substantial differences in concentration among pits are found, however.

There are several valid reasons to try to separate the liquid and solid fractions of manure. Unfortunately, the most effective separation methods are expensive and actually add material to the manure. Therefore, the selection of a liquid-solid separation system must address the overall goals of the production facility and practical cost constraints[1].

Here are some of the more common reasons for utilizing liquid-solid separation of swine manure. *Reduce loading rates on liquid-based treatment systems.* Breakdown of the volatile solids is also responsible for much of the manure odor. Much of the phosphorus in the manure – 96% -- is in the solids fraction (Rice et al. 2003), and of that solids fraction, the phosphorus predominates in particle sizes too small to capture in mechanical screens. Soluble phosphorus can be precipitated from the liquid stream through further processing, but at this time the particulate phosphorus is of more interest to the engineering community addressing phosphorus extraction. Nitrogen is split about half-and-half between liquids (the ammonium fraction) and solids (the complex organic fraction). Potassium is largely soluble and is distributed fairly evenly throughout liquid and solids. *Partition phosphorus to move it off-site.* As producers and regulators become more conscious of phosphorus imbalances on cropland and attendant buildup of P in soils, the amount of cropland available to any given farm for land application of manure is reduced. Removing a large fraction of the phosphorus from manure into a solids stream that can be economically transported is therefore very attractive to many farms. *Improve handling characteristics of the liquid.* Lagoon recycle flush systems with solids

[1] The reader is referred to the thorough discussion of liquid-solid separation techniques and performance of systems that is found in MWPS (2001).

separation can supply the lower-solids-content liquid to irrigation systems that use small diameter, plug-prone nozzles. *Lengthen interval between sludge cleanout of liquid treatment systems.* Inconvenient and expensive de-sludging operations can be postponed by using settling tanks or other simple separation techniques. *Produce a targeted-market product; for example, composting solids.* For many production facilities composting warrants consideration. *Create another farm enterprise using the separated stream.* Vermiculture (earthworm production) using composted manure solids is a way to generate additional farm income from an otherwise low-value material.

Characteristics of separation equipment

Cost and complexity have removed most industrial separation equipment from consideration for the livestock production market. Municipal waste treatment plants, food processing waste plants, and many other applications have the resources needed to install, operate and maintain elaborate liquid-solid separation systems, some of which could be otherwise suited for livestock manure. At the same time, many people in the non-agricultural public have the mistaken belief that municipal waste treatment processes are, money considerations aside, all automatically adaptable to livestock manure treatment. Manure is orders of magnitude more concentrated than municipal sewage, however, and therefore most sewage treatment installations would fail miserably at treating raw undiluted manure.

Some university studies have successfully piloted and improved upon an Asian based system for keeping urine and feces separate after excretion. The rationale is that, if particulate phosphorus removal is one of the main drivers for using liquid-solid separation, why mix the phosphorus-rich feces stream with the nitrogen- and potassium-rich urine in the first place? A Michigan State University study found that a sloping-pit-floor approach, which allows the urine and wastewater to drain away from feces and the solids to be periodically scraped to a receiving channel, could capture 90-97 percent of the phosphorus produced in the solids fraction (Tengman and Person 1995). North Carolina State University's sloping-belt system under slotted floors (Fig. 1) performed similarly (Rice et al. 2003). This separation performance is about as good as can be attained with the best chemical-augmented separation technology that starts with a mixed manure stream. Odors from the buildings that use such manure-urine segregation construction are greatly reduced as well, since anaerobic decomposition of the manure does not have a chance to become established.

Methods to increase solids removal effectiveness and throughput

To improve the percentage of total solids removed from the mixed manure stream, there are a few basic techniques.

Separate as soon as possible. The fresher the manure, the easier it is to separate. (Zhu et al. 2000).

Keep particles as large and heavy as possible. By mixing fluids that contain charged particles into the liquid, the smaller manure solids particles tend to agglomerate and

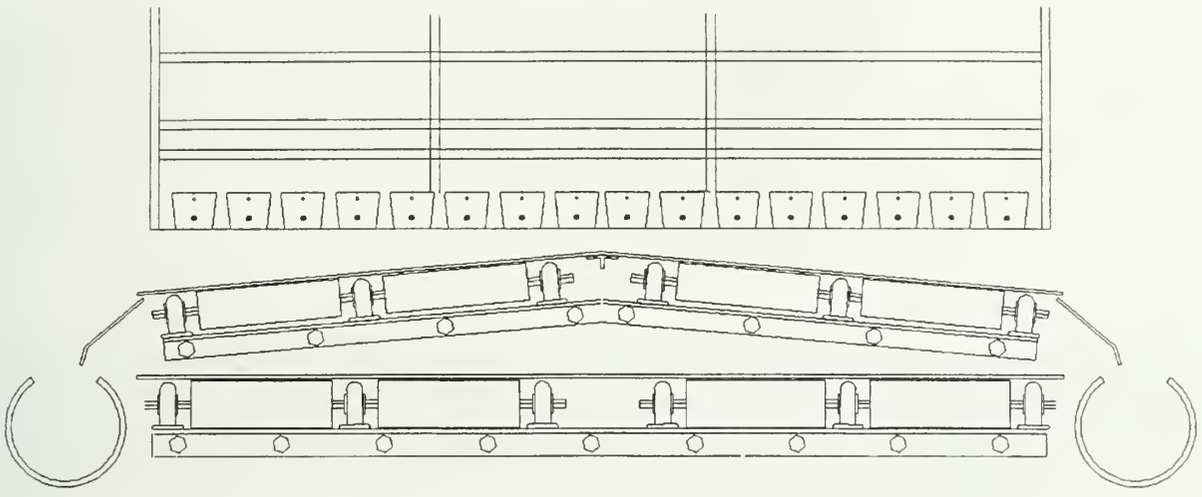

Figure 1. Cross section of belt liquid solid separator under slotted floor pen. Smooth plastic belt travels on rollers perpendicular to the plane of the drawing, and feces is scraped off belt at one end. Urine and waste water drain readily to pipe channels and to liquid storage.

become large enough to settle out, squeezing the trapped water out of the mass as they go through the process.

For gravity settling: decrease turbulence; increase gravity (centrifuge); add flocculant, precipitant, or coagulant; increase detention time; compact the solids.

For mechanical screening: decrease mesh size to increase throughput; vibrate the screen to keep larger particles from blinding the screen openings; add flocculant, precipitant, or coagulant.

Factors that increase throughput usually work in opposition to obtaining better separation efficiency. For example:

Settling: increase settling tank size or number of tanks; centrifuge; reduce detention time; removal solids continually and recycle liquid.

Screening: increase number and/or area of screens; increase mesh size; screw press, belt press, centrifuge, vibrate.

Gravity liquid-solid separation

The simplest method for liquid-solid separation is gravity settling in a tank or other vessel. Compared to mechanical separators without chemical augmentation, gravity

settling can usually attain better solids removal efficiency (MWPS 2001). The drawback to most gravity systems is that the solids must be removed batchwise and the solids fraction is much wetter than solids coming from most mechanical separators.

The attraction of gravity settling systems is even greater with the possibility of continuously removing solids from the settling tank. Experience and studies (e.g. Zhu et al. 2000) have shown that settled solids on the tank bottom tend to become re-suspended, at least partly due to anaerobic digestion and gas release. Therefore, removing solids regularly and often from the gravity settling system can increase solids removal efficiency.

Objectives

The objective of this study was to use a laboratory scale settling tank to determine the optimum settling tank bottom angle (angle of repose of solids), optimum retention time, and optimum solids percentage of the incoming manure stream. A system for continuously removing solids by way of an auger and pump was explored.

Approach

A series of experiments was conducted with a laboratory-scale settling tank. A tank was built simulating a section of a settling tank; liquid swine manure was circulated through the tank, using peristaltic pumps, with a solids-enriched stream being drawn from the tank bottom and a more liquid stream overflowing the top (Fig. 2). A cross-auger was installed in the lowest corner of the tank, to help direct the settled solids into the removal port of the tank.

Two measurement parameters were set for the experiments. One, the solids separation quality, was a measure of the greatest solids content expected from a quiescent settling at the bottom of the tank. The other, sedimentation efficiency, was a measure of the effectiveness of the tank in separating the slurry into mostly-liquid and mostly-solid streams. Retention times were picked to represent a typical range of operating conditions for field applications. Samples of the influent, effluent and solids streams were collected and analyzed for solids content, TKN, total phosphorus, and potassium.

Figure 2. (Left to right) Slurry agitation and supply, settling tank, solids removal pump and reservoir.

RESULTS

The optimum slope of the tank bottom (that is, the solids angle of repose) was shown to be about 35 degrees from horizontal (Table 1 and Figs. 3 and 4). The amount of solids leaving the tank in the

overflow effluent could be reduced by almost half, using gravity and the continuous solids removal, with no further treatment. The retention time of 30 minutes was optimal for the tank configuration tested.

Table 1. Optimum parameters for settling tank construction and operation.

Slope of tank floor, deg.	Retention Time, minutes	Initial solids percentage	
Optimum parameters for sedimentation efficiency			Total solids sedimentation efficiency, percent
35	60	3	51.7
Optimum parameters for solids separation quality			Total solids separation quality, percent
35	20	5	22.5

Fine settleable solids tend to settle in a very porous "sponge" formation (Fig. 5) making it inefficient to remove those solids directly. The auger removal device was placed in the tank to help compact those solids and improve sedimentation efficiency by dewatering the fine solids matrix. Coarse solids appeared to be made up largely of pieces of undigested cellulose material and ash (Fig. 6), settling into a more compact matrix containing somewhat less water.

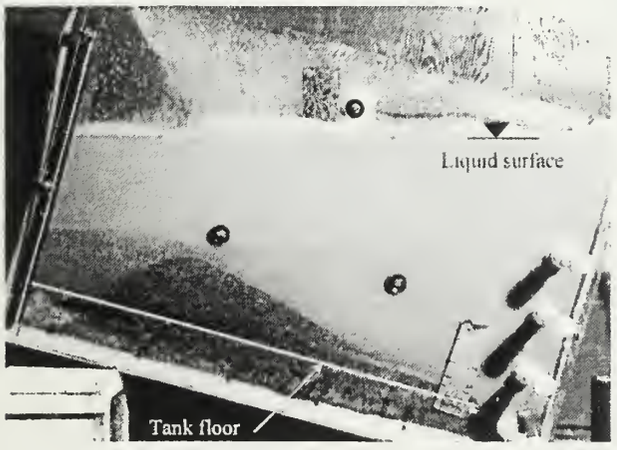

Figure 4. 15 deg. slope 60 minute retention 3% solids during removal

Figure 3. 35 deg. slope 20 minute retention time 5% solids, showing solids reposing at same 35 deg. angle as tank bottom.

Charts of the concentration ratios of the sampled parameters (Figs. 7, 8, and 9) summarize the ability of the gravity tank to remove constituents in the solids stream.

Figure 5. Fine manure solids matrix after gravity settling.

based on the solids content of the incoming manure stream. Note that the actual solids contents of the influent streams, while the experimental parameters were set at 1%, 3% and 5% solids and the "stock manure" was diluted by formula, were actually shown to be closer to 0.8%, 3%, and 8% solids when samples were evaluated in the laboratory. As demonstrated by the charts of concentration ratios, total solids are the easiest to segregate by settling; total nitrogen is next easiest; total phosphorus is next, and potassium is the most difficult to remove by settling. With 1% solids manure entering the tank, settling was able to concentrate total solids more than 20 times; total Kjeldahl nitrogen more than 5.5 times, and total phosphorus more than 5 times. However, with the highest solids concentration manure (about 8%) entering the tank, phosphorus was concentrated in the solids only 13% to 18%. Retention time in the tank – 60 minutes v. 20 minutes – had little effect. The tank floor slope did not affect phosphorus recovery consistently, with the shallower slopes sometimes giving more phosphorus in the solids stream coming from the bottom of the tank and other times less. With the highest concentration of solids in the influent stream, phosphorus recovery was best with the shallower slope, implying that with a steeper tank bottom slope, the heavier, easily settled solids slid downward and blocked the exit for the smaller, phosphorus-rich solids. That emphasizes the importance of continuous solids removal from the tank, to enhance the capture of fine solids as well as the coarse ones.

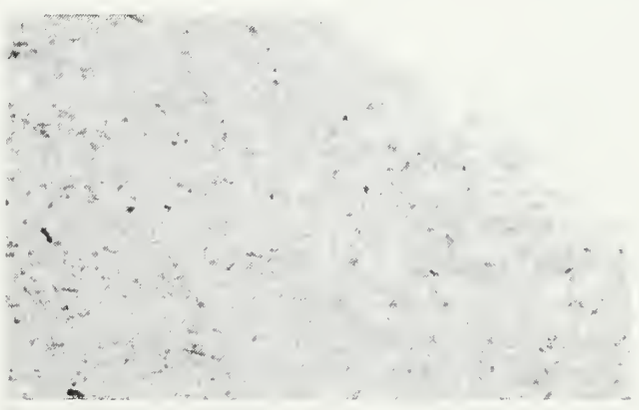

Figure 6. Coarse manure solids after gravity settling.

Implications

Results show the operating ranges to design for, and performance to expect, from a gravity tank with continuous solids removal. Such a component could be incorporated into other systems. For example, the maximum solids separation quality of approximately 20% is optimum for feedstock to a thermochemical conversion process (He et al. 2001). Fine solids remaining suspended in the supernatant from the gravity separation could be more efficiently flocculated (and with less addition of costly chemical, since no chemical would be wasted on the solids that were easily settleable by gravity) and separated in another gravity or mechanical separation apparatus (Fig. 10).

Vanotti et al. (2002) indicated a linear function of PAM (polyacrylamide) addition required to remove the suspended solids, and that about 0.75% is needed for 2.5% TSS manure. At $2.00 per pound of PAM, they estimated a minimum chemical cost of $1.27 per pig to effectively separate solids and nutrients from flushed liquid manure, using a screen separator. Our experiment shows that the addition of a simple gravity separation system as a first stage might substantially reduce the amount of chemical, thus the variable cost of the operation; and 50% reductions of chemical costs if costs are linearly related to total solids in the manure (not necessarily total suspended solids) could be attained.

Publications

Polakow, J.A. 2001. Gravity liquid-solid separation with continuous solids removal system. Master's thesis. University of Illinois at Urbana-Champaign.

Acknowledgement

Financial support of the Illinois Council on Food and Agricultural Research is gratefully acknowledged.

REFERENCES

He, B.J., Y. Zhang, Y. Yin, T.L. Funk, and G.L. Riskowski. 2001. Feedstock pH, initial CO amount, and solids content effects on the thermochemical conversion process of swine manure. Transactions of ASAE 44(3):697-701.

MWPS. 2000. Manure characteristics. MWPS-18 Section 1. MidWest Plan Service, Ames, IA.

MWPS. 2001. Livestock and poultry environmental stewardship curriculum. MidWest Plan Service, Ames, IA.

Rice, M., C. Baird, F. Humenik, J. Classen, S. Liehr, K. Zering, E. van Heugten. 2003. Belt system for manure removal. In, Proceedings of the North Carolina Animal Waste Management Workshop, Oct. 16-17, 2003. Research Triangle Park, NC. North Carolina State University, Raleigh, NC. pp. 45-47.

Tengman, C.L. and H. Person. 1995. Gravity flow liquid-solid separation concentrating swine manure phosphorus in solids. In, Proceedings of the 1995 Livestock Waste Management Conference. University of Illinois Extension. Urbana, IL.

Vanotti, M.B., D.M.C. Rashash, P.G. Hunt. 2002. Solid-liquid separation of flushed swine manure with PAM: effect of wastewater strength. Trans. ASAE 45(6):1959-1969.

Zhu, J., P. M. Ndegwa, and A. Luo. 2000. Changes in swine manure solids during storage may affect separation efficiency. Applied Engineering in Agriculture 16(5):571-575.

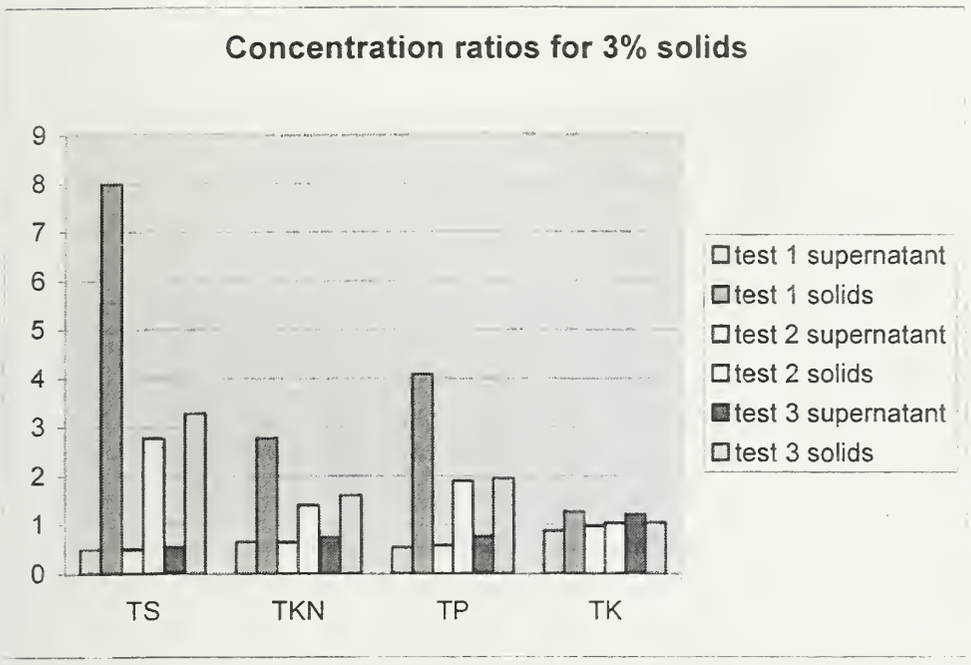

Figure 7. Concentration ratios for liquid-solid separation experiments using 3% solids manure influent.

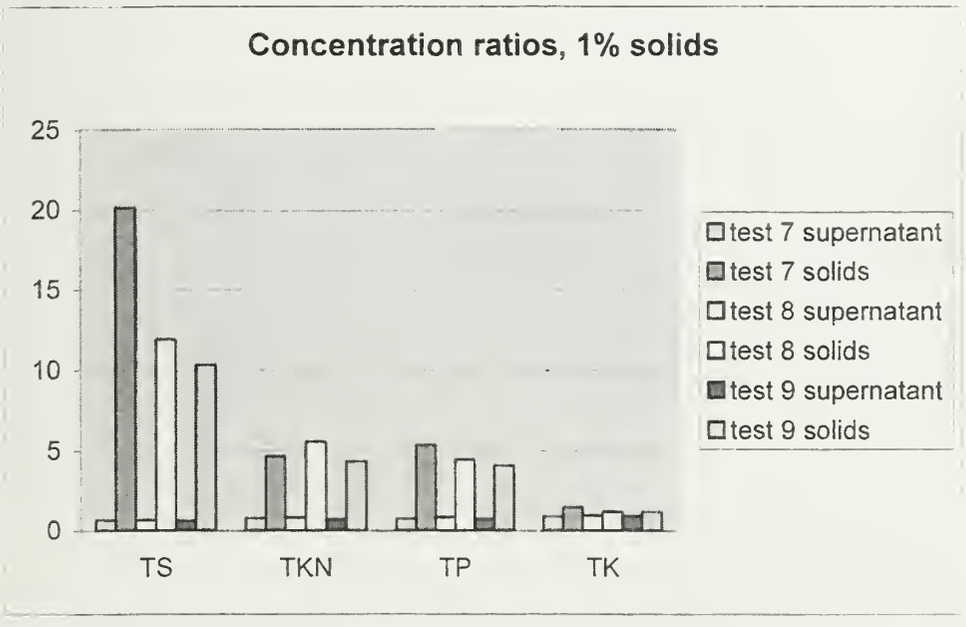

Figure 8. Concentration ratios for liquid-solid separation experiments using 1% solids manure influent

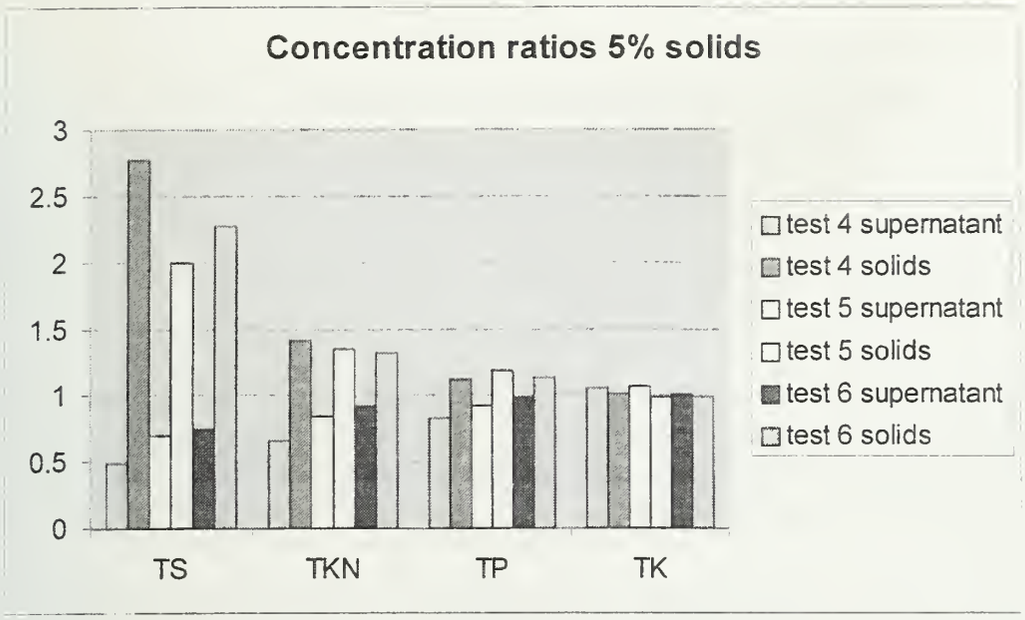

Figure 9. Concentration ratios for liquid-solid separation experiments using 5% solids manure influent

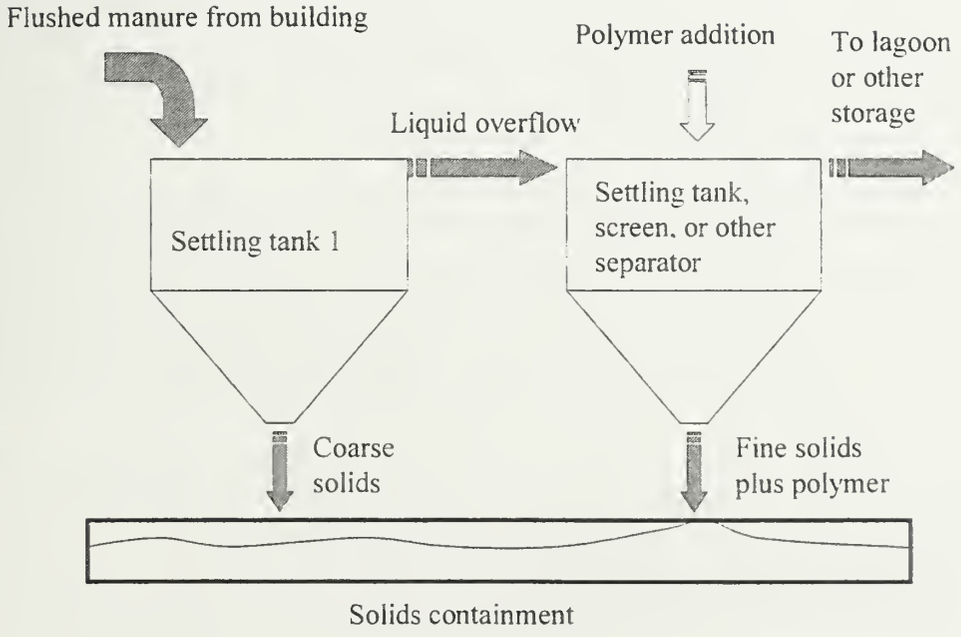

Figure 10. Dual stage liquid-solid separation using gravity settling plus a polymer treatment step.

Point-source Pig Manure-management Processes in Denmark

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The National Committee For Pig Production
Danish Meat & Bacon Council

Danish farmers produce close to 24 millions pigs per year. 85% of this production is exported, and this makes Denmark one of the world's largest exporters of pigmeat. It also makes pigmeat the country's most important export product at around 6 % of total value.

Family holdings and "owner occupiers" are commonplace in Danish farming. Pig production is no exception, and Denmark has about 12,000 such producers. Over the years, larger producers have replaced the smaller ones. But in spite of fewer producers, production has nearly doubled since 1970. 30 % of the producers now account for more than 80 % of total production.

The co-operative system plays a significant role in Danish agriculture. Around 95 % of Danish pigs are slaughtered, processed and marketed by co-operative societies, owned and managed by the pig producers. Much of the further processing and other affiliated industries are also run on co-operative principles. Statistics on the Danish agricultural production is given in table 1.

Table 1. Statistical data on Danish agricultural production	
Total area of Denmark, hectare	4,400,000
Agricultural land, hectare	2,676,000
Permanent grassland, hectare	172,000
Set aside, hectare	190,000
Number of dairy cows	661,000
Production of milk, ton	4,664,000
Number of sows	1,112,000
Number of produced pigs	23,985,000
Number of hens	1,112,000
Eggs produced	79,000
Poultry – produced meat, ton	203,000
Livestock total, animal units (AU)	2,349,000
Total Nitrogen in animal manure, ton	230,000
Total Phosphorus in animal manure, ton	49,000
Total Potassium in animal manure, ton	151,000

The Danish regulatory system

Danish farmers are subject to a series of laws and rules regarding the environment. Environmental rules set limits to the number of pigs that can be produced by an individual herd. The Danish regulatory system is based on animal units (AU). One AU is the number of pigs on partly slatted flooring that produce 100 kg of nitrogen (N) in livestock manure (ex slurry tank). A "critical size" for a pig farm is 250 AU, which equals a sow unit with 1150 sows producing piglets at 7 kg or a hog unit with a yearly production of 9000 hogs 30 to 100 kg.

The local authorities must approve any expansion of pig production. For an expansion up to 250 AU it typically takes 4 to 12 months to get the permission. In the meantime the local authorities calculate ammonia emissions, the nitrate and phosphorous depletion from cropland upon spreading the slurry. In this process they evaluate the effect of the expansion on vulnerable nature, groundwater, lakes, rivers etc. If the authorities find that the pollution from the expansion exceeds the limits they have put on nature, groundwater and the water environment in general the pig producer must change his project. The time to get the permission also include a public hearing lasting 4 weeks.

Every single pig farmer in Denmark is not allowed to have more than 750 AU. If pig farmer at one site expand his production beyond 250 AU the farmer need a special permission, which typically takes 1 to 2 years to obtain. Therefore the typical way for the Danish pig farmer to expand is by having three sites with up to 250 AU.

Harmony area

A balance between the number of animals in the herd and the land available on which to spread slurry is required. For each 1.4 AU the pig farmer need 1 hectare (10,000 m^2) of land for spreading the slurry. It is called the harmony area. There is also a rule saying the pig farmer needs to own a certain amount of the land for harmony. Up to 120 AU the pig farmer must own 25 % of the harmony area. Between 120 and 250 AU the pig farmer must own 60 % of the harmony area and beyond 250 AU he must own the entire harmony area.

Spreading of slurry

There are also fixed seasons for slurry spreading. It is forbidden to spread slurry in the period between harvest and February 1. Exception from this rule is crops like winter rapeseed where you can spread slurry in the autumn until October 1. In general, slurry contains important nutrients, which the plants can best absorb in the spring. Therefore most of the slurry is brought out on growing crops from March to May.

Broad spreading of slurry was banned August 1, 2003. In crops like winter wheat, winter barley and winter rapeseed the slurry is brought out with trailing hose technique as shown in figure 1. This technique gives an accurate spreading of slurry and compared to broad spreading it reduces ammonia losses and odour emissions. In crops like spring barley and oats some of the slurry is injected into the ground. There are also mandatory storage facilities for slurry to make sure each pig farm has enough capacity for at least 9 months of storing.

Figure 1. Spreading of slurry on winter wheat with different types of trailing hose technique

Fertiliser plans

Each farm must have a fertiliser plan. For each crop you calculate the amount of nitrogen, phosphorous, potassium and some other minor nutrients needed. Due to a governmental act on reducing nitrate depletion from the soil there are limits on nitrogen application. Today the limit is set 10 % below the economical optimum for nitrogen application. The same act has also put a demand on utilization of nitrogen in livestock manure. This demand has increased in the last decade. Today 75 % of the nitrogen in the slurry has to be calculated into the fertiliser plans. Table 2 shows a typical Danish fertilizer plan for crops like winter wheat, sugar beat and spring barley on a pig farm.

This dramatic increase in utilization of the nitrogen in livestock manure has had a significant influence on the total consumption of mineral fertiliser used by the Danish farmers. Figure 2 shows the total consumption of mineral nitrogen since 1985.

Table 2. Example of a typical fertiliser plan for a pig farmer

Crop	Hectare	Nitrogen quota Kg per ha	Total quota Kg N
Winter wheat after cereal	50	167	8,350
Sugar beat	25	104	2,600
Spring barley	25	107	2,675
Total	**100**		**13,625**
Yearly production 5,000 hogs 30 to 100 kg Yearly production of Nitrogen: 5000 hogs x 2.67 kg N per hog = 13,350 kg N Demands for utilization: 75 %			10,013
Nitrogen quota: Mineral fertiliser		**36**	**3,613**

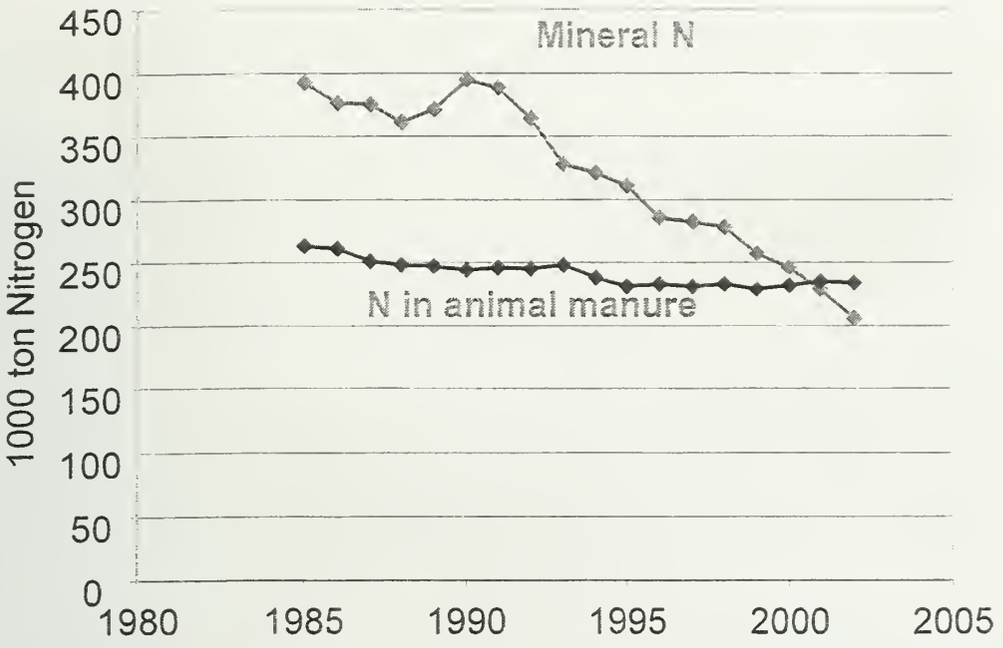

Figure 2. Total consumption of mineral nitrogen and the nitrogen content in animal manure in Denmark since 1985.

Pig manure management

Quite a number of companies are developing and marketing different ways of treating pig manure. The purpose is to reduce odour and ammonia losses from storing and spreading the slurry, reduce the volume of the slurry and improve the utilization of the nutrients in the slurry. New legislation on separation of slurry to enhance new technology reduces the amount of land a pig farmer has to own for a certain production. This legislation chooses between low technological separation and high technological separation.

Acidifying slurry by adding sulphuric acid

The Danish farmer and inventor Jens Oestergaard has developed a new method of acidifying the slurry. This waste handling system is now patented and marketed by the Danish company Staring Maskinfabrik A/S. The objective of his invention was to reduce ammonia emissions not only from animal houses but also from storing and field application of slurry. Thereby as a side effect hopefully the odour emissions would be reduced too. By the end of 2004 the company will have 24 acidifying plants operating on Danish farms.

It is well known from many studies and basic chemistry that reduction of pH reduces ammonia emissions. Over the years, several ways of reducing pH have been tested (Pedersen, 2003). Although there has been a significant decrease in pH and ammonia emissions, none of the tested systems have been successful from a commercial point of view so far.

In this newly developed waste handling system, slurry is acidified in a special way. Outside the building at the bottom of a small storage tank, concentrated sulphuric acid is added at a ratio of approximately five kg per tonnes of slurry. The amount of sulphuric acid is controlled by a pH-sensor. After a resting period – typically 10 minutes - a pump stirs up the treated slurry. Simultaneously, waste is aerated by injecting compressed air to prevent sulphate-ion changing

into noxious hydrogen sulphide. This treatment reduces pH to about 5.5 and also improves the fluidity of the slurry as some of the dry matter content is degraded.

Eventually the treated slurry is used to flush the waste pits and ensure that pH in the waste pits is kept at about 5.5. The number of flushings can be varied. Typically, the waste pits are flushed four to eight times a day.

The system is automatically controlled. Therefore every parameter can be varied freely. Figure 3 shows the treating system for acidifying slurry.

The results have so far shown that the newly developed acidifying system seems very efficient in reducing ammonia emissions from pig houses. In hog systems with fully slatted flooring a reduction between 70 and 80 % in ammonia emissions is reached. Unfortunately, the system does not have same potential for odour reduction. In case of breakdown and the acidifying stops for a period of time there seems to be a significant risk of an increase in odour emissions.

From a fertilizer and plant nutrient point of view, the system contains important features, which are about to be evaluated. Preliminary results have shown that pH sustains at approx. 5.5 during the storage period and also when the slurry is applied to the plants. Therefore it seems possible to obtain a significant decrease in ammonia losses from animal production facilities with this newly developed acidifying system.

Figure 3. The system for treating slurry with sulphuric acid. The tank has a capacity of 3 cubic metres – enough for storing five tonnes of concentrated sulphuric acid. In front of the tank there is a cabinet including a control unit for controlling addition of sulphuric acid and compressed air. From the cabinet, tubes lead to the bottom of the storage tank, which is situated right in front of the green container.

Separation of pig slurry by adding chemicals

Some Danish companies separate pig slurry by adding precipitations agents and flocculants. During this treatment a solid part is separated as shown in figure 4. This process removes 60 - 80 % of the phosphorous and 20-30 % of the nitrogen from raw pig slurry. If the same process is done on acidified slurry it is possible to remove nearly all the phosphorous from the slurry.

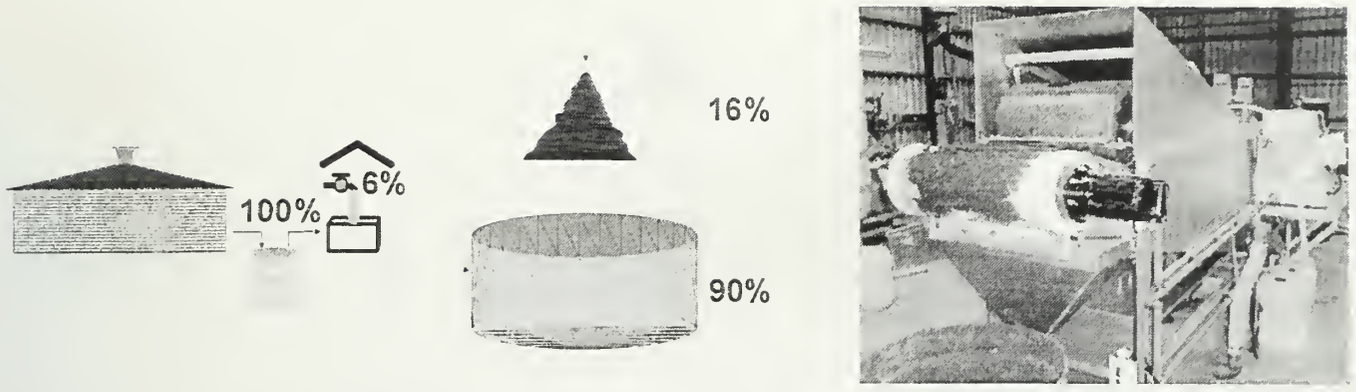

Figure 4. Separation of pig slurry by adding precipitations agents and flocculants.

Separation of pig slurry by stationary and mobile decanting centrifuge units
Decanting centrifuge is a well-known technology for separation of sludge. Especially in the Netherlands decanting centrifuge is also used for separation of pig slurry. In Denmark some pig farmers have purchased small stationary decanting centrifuges. Because of economics of scale and the high capacity of a decanting centrifuge, typically 50-100,000 cubic meters per year, mobile decanting units are the cheapest solution for the typical Danish pig farmer.

A decanting centrifuge separates 60-80 % of the phosphorous and 20-30 % of the nitrogen from pig slurry.

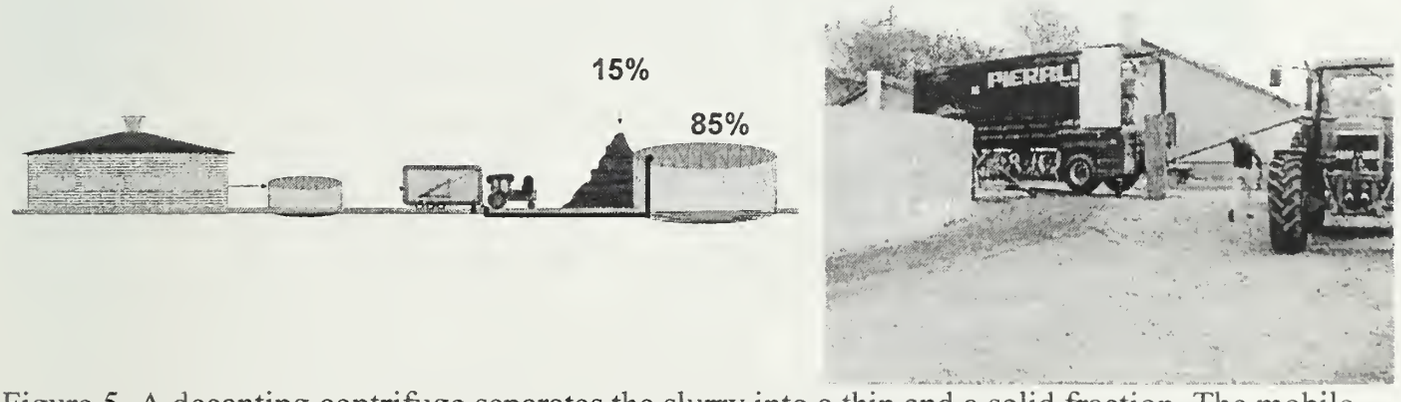

Figure 5. A decanting centrifuge separates the slurry into a thin and a solid fraction. The mobile unit shown above has a capacity of 20 cubic meters per hour. Decanting centrifuge is quite power consuming, therefore the mobile unit needs its own generator.

Funki Manura 2000
This system is a high technological separation unit shown in figure 6. Altogether the company has two separation units running in the Netherlands and one in Denmark. This unit runs quite well but it is too expensive. Therefore the company has stopped the production.

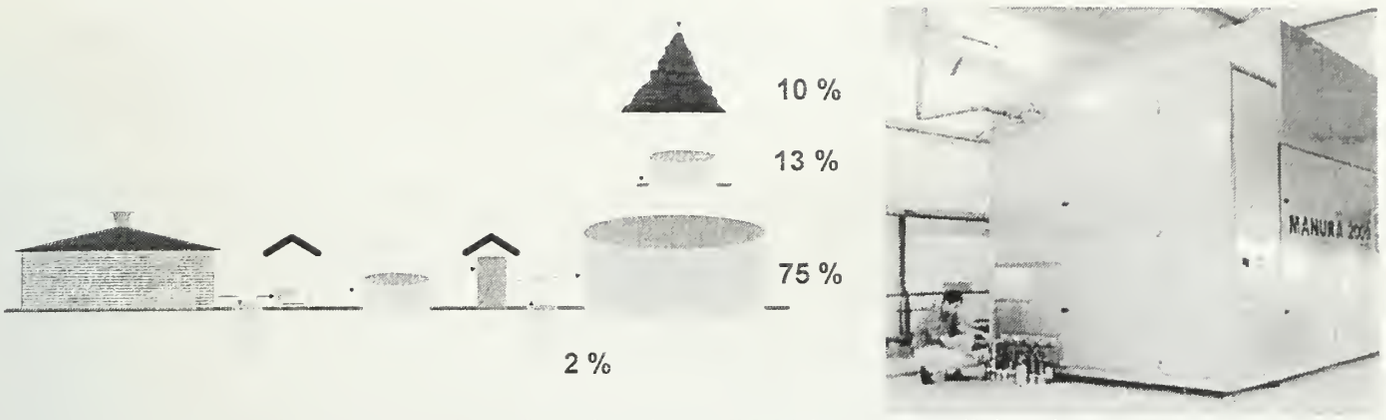

Figure 6. The slurry is separated into four fractions: 75 % in a "water" fraction, which can be irrigated on grassland, 2 % in a NPK-fraction, 13 % in a N-fraction and 10 % in a humus fraction. The separation system is based on a decanting centrifuge and evaporation techniques.

Green Farm Energy

Green Farm Energy is high technological separation concepts for treating slurry and organic waste from agricultural industry. The cost of a plant is 40 to 80 million DKK (6.5 DKK = 1 US$). Even though the company has sold four separation units in Denmark - two working and two under construction – still no results show that the system works a prescribed. A crucial point in the economics is the amount of biogas produced. In Denmark electricity produced on biogas is subsidised by the government. The price is 0.6 DKK per kWh.

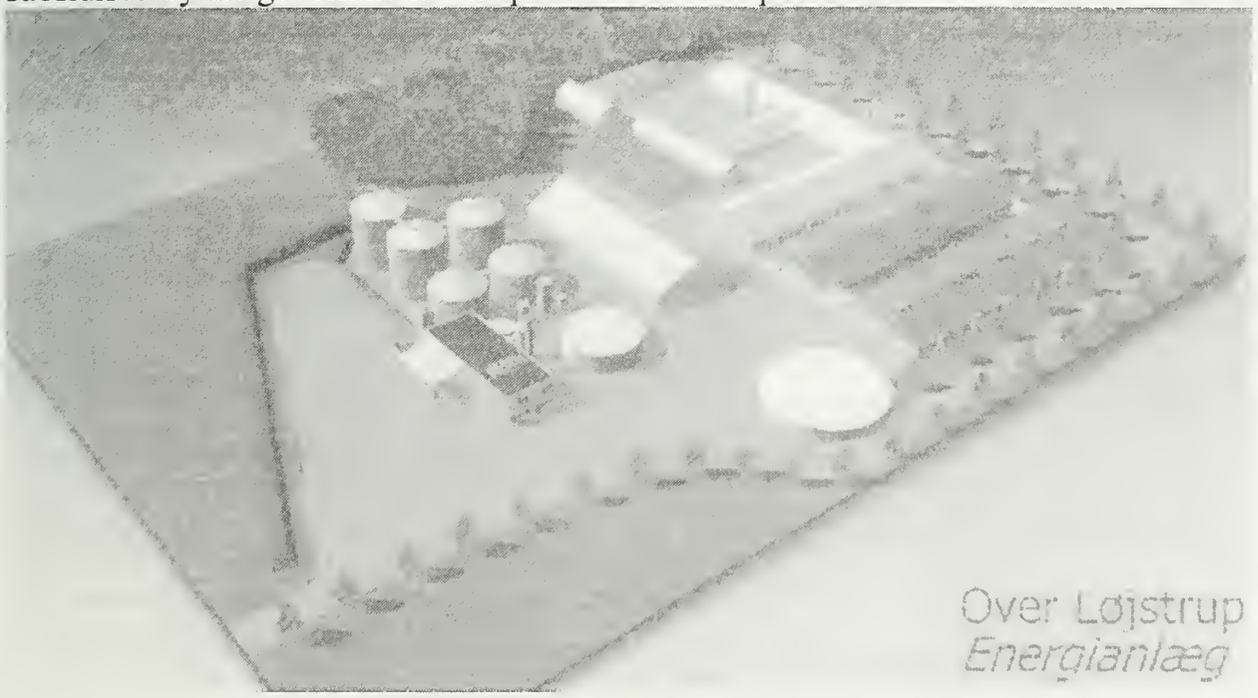

Figure 7. In the Green Farm Energy concepts the organic waste is treated prior to biogas fermentation by alkali hydrolysis e.g. boiling at 160 degrees Celsius, 6 Bar and a pH about 10. After half an hour the organic matter is cooled down to 80 degrees Celsius by adding slurry. In the next step ammonia is stripped off and the suspension is ready for biogas fermentation and separation.

Reduction of ammonia and odour emissions from pig houses
The National Committee For Pig Production performs a number of studies on techniques to reduce ammonia and odour emissions from pig houses. A few are presented in this paper.

Air cleaning - microbiological
The Danish ventilation company SKOV and the company Perstrup Betonindustri have invented a new air cleaning system. It is a two-step air cleaning system. The air from the pig house passes through two filters. The first filter removes the dust. Both filters are moisturized periodically with water circulating from the tank. In this water and on the filters there is significant biological activity, which degrades a lot of the organic matter originating form the dust. It is possible to run the filters for months, without changing the water, but it will also reduce the performance of the filters.

Preliminary results show that the filter is very efficient in reducing ammonia and odour emissions. The odour concentration is reduced significantly and the character of the odour is changed so you hardly can smell pigs at the farm – only the faint smell of the filters.

There are different ways to lead the air from the pig house to the central air cleaning system as shown in figure 9 and 10.

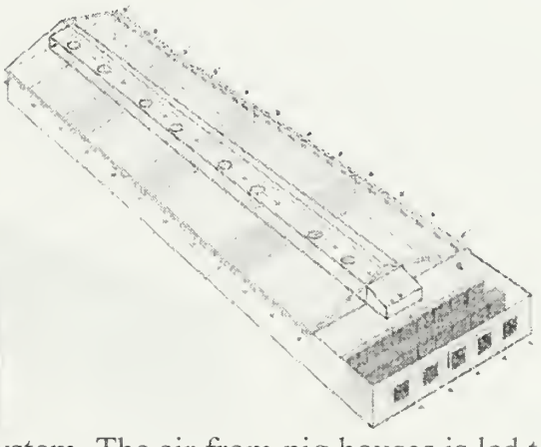

Figure 9. Pig house with an integrated air cleaning system. The air from pig houses is led to the filter through an insulated ventilation duct in the attic space.

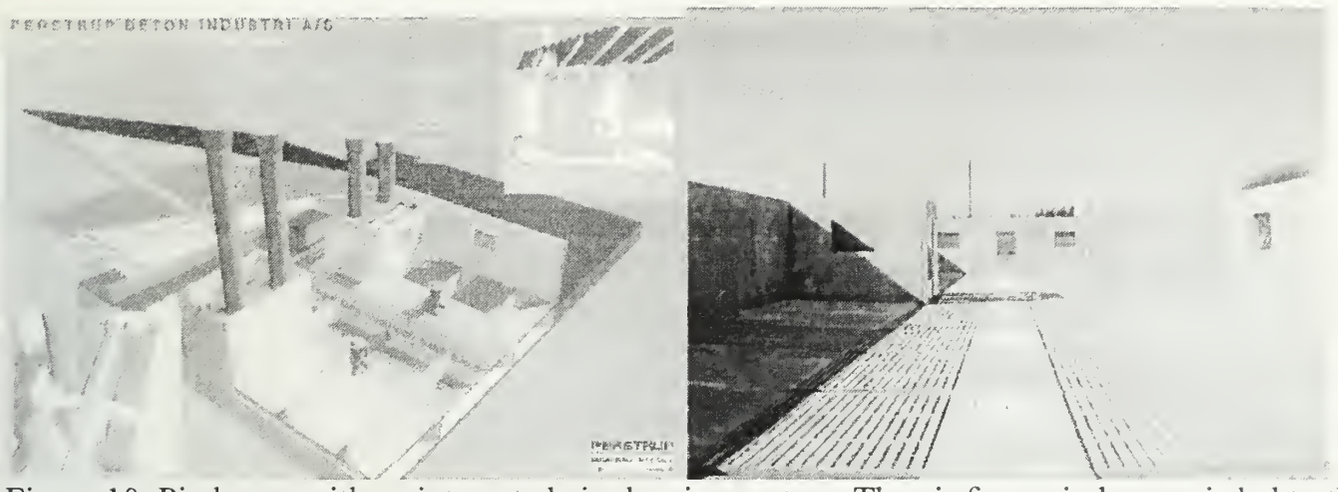

Figure 10. Pig house with an integrated air cleaning system. The air from pig houses is led to the filter through a canal beneath the solid floor.

Air cleaning - chemical

The Danish company Scan-Airclean has invented a new air cleaning system shown in figure 11. The air from the pig house passes through filters moisturized periodically with diluted sulphuric acid with a pH at about 4. Preliminary results show that this system is very efficient in reducing ammonia emissions from the outlet air. Unfortunately, it is not very efficient in reducing odour emissions.

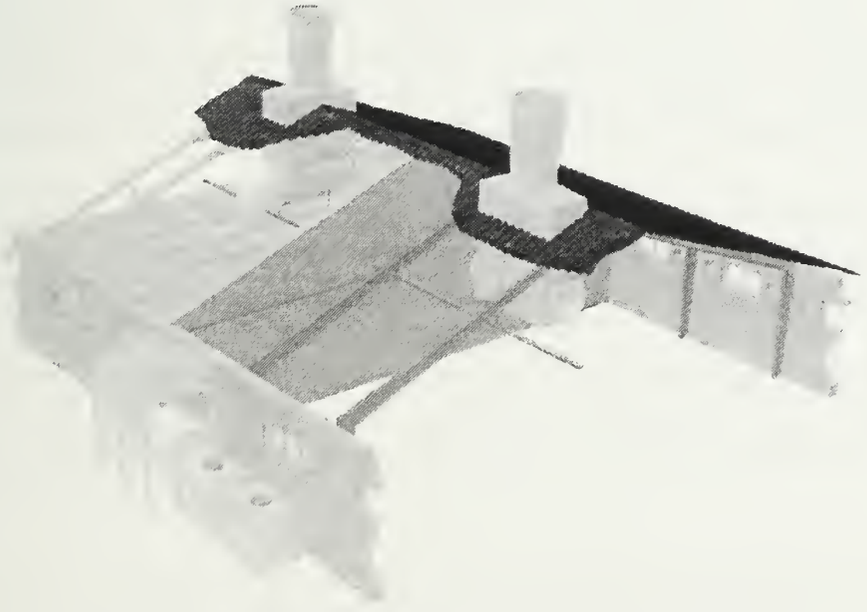

Figure 11. Air cleaning system from Scan-Airclean. The ammonia emissions are reduced by more than 90 %. The ammonia is collected as ammonium sulphate in the tanks outside the pig house.

REFERENCE

Pedersen, P., 2003: Reduction of gaseous emissions from pig houses by adding sulphuric acid to the slurry. Proceeding for CIGR Symposium June 1-4 2003 Bygholm Denmark.

Managing Emissions from Swine Facilities: Current situation in The Netherlands and Europe

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INTRODUCTION

Animal production has become highly specialized, industrialized and concentrated geographically in various parts of the world. In Europe swine production volumes strongly increased over the last decades. In Europe main swine producing areas can be found in the north (e.g. Denmark, the Netherlands, Belgium, Brittany in France, Niedersachen in Germany) and the south (Lombardy in Italy, Catalunia and Galicia in Spain; Figure 1). Expansion and specialization have enabled higher productivity level at the farms. New housing systems and improved feeding and manure management methods have been introduced to increase the efficiency and volume of animal production and labor productivity. This process of expansion and specialization has, without doubt, improved farmers' living standards in recent decades. However there are drawbacks in this process of intensification that are related to animal welfare and health issues and, especially where swine production has been concentrated in restricted areas (Figure 1), environmental pollution. Concern has been growing about the environmental effects of gases emitted from livestock production systems causing nuisance in surrounding residential areas and affecting natural ecosystems by eutrophication and acidification.

Odorous gases from livestock houses, manure storages and from manure during and after application on the field has received increasing attention from the 1970's on. This is caused by the mentioned intensification of animal production on one hand and the strong urbanization in these areas on the other hand (Tamminga, 1992). In the densely populated Netherlands pig production is concentrated in the east and south, here reaching levels of over 2000 pigs per km^2. The main problem of odor is its nuisance for people in the vicinity of the farm. In the Netherlands, an odor regulatory system based on setback distances and odor source strength has been applied since 1972.

More recently, attention also has been focused on gases that are detrimental for the environment, e.g. ammonia (NH3) and greenhouse gases. A significant part of the N-input in pig production is emitted as ammonia, under European conditions estimated at 30% both from animal houses and from application of manure (IPPC, 2003). The regional deposition of N from this abundant alkaline gas eventually causes, in a chain of conversion processes, acidification and eutrophication in ecosystems (vanBreemen et al., 1982). In many parts of the east and south of the Netherlands, critical depositions loads in nature reserves are considerably exceeded. Similar problems play in other pig concentration areas in Europe. Besides atmospheric leaching of N to the environment in these concentration areas, the pressure of large manure volumes leads to high application levels of animal manure and consequently leaching of N (as nitrate) and P (as phosphate) to ground and surface water. Nitrate concentrations in groundwater in these areas,

like in the east of the Netherlands, exceed the 50 mg/l threshold that is set by the European Nitrate directive.

In this paper attention will be focused on how emissions from swine facilities can be managed by producers, and in narrow relationship with it, are regulated by authorities given the available management options and environmental targets. European approaches and research in new swine housing systems and management, and the regulatory approach on national and European level are highlighted, with special emphasis on the developments in the Netherlands. The next sections will deal first with an overview of the regulatory framework, followed by measurement methods for odor and ammonia that are used for assigning emission factors in regulations, options for reducing odor emissions in the production chain, and finally examples of new low-emitting swine housing systems and future perspectives in managing emissions in swine production.

Regulatory framework for emissions from intensive livestock facilities

In Europe a major and still increasing part of legislation is defined by European Union (EU) directives to which national legislations of the member states have to comply. Member states are in a continuous process of modifying their national legislation in compliance with new EU directives, each within their own legislative framework. In addition, states have their own local legislation that may differ considerably between each other. This section deals with the three most important EU directives for environmental protection in relation to intensive livestock production, followed by national regulations to prevent odor nuisance.

IPPC Directive

In 1996 the Integrated Pollution Prevention and Control (IPPC) Directive was set out by the EU Council. IPPC aims at controlling the effects of large swine facilities and a wide range of other industries on the environment. It does so by preventing, and if not economically possible, by reducing emissions to air, water and soil, and by making efficient use of resources. The IPPC Directive provides for a permitting system for categories of industries requiring both producers and regulators to take an integrated, overall look at the polluting potential and the water and energy use of the industry. The overall aim is to ensure a high level of protection for the environment as a whole. Central to this approach is that producers should take all appropriate preventative measures against pollution by the application of so called 'best available techniques' or BAT (IPPC, 2003).

For swine production, facilities that house more than 750 breeding sows or more than 2000 fattening pigs are subject to IPPC. In practice this means that the majority of pig farms in Europe are excluded, however in the concentration areas with specialized large scale pig facilities producers are or will be subject to a licensing system in compliance with IPPC. All sorts of emissions are covered by the rules: mineral emissions in manure application, dust, noise and ammonia and odor emissions as related to buildings and slurry storage and spreading. The IPPC requirements affect the whole of the production cycle, from feed intake up to the end products. The key issue for farmers to obtain a production permit is that they have to demonstrate the use of BAT, both in management practices and in the design and maintenance of buildings and equipment. The impact of IPPC on pig production and environmental protection is mainly determined by the definition of BAT. An EU Technical Working Group recently has completed the first reference document for poultry and pig production that describes the currently accepted

BAT's, thus defining the European state of the art of management practices and housing systems that protect the environment and are economically viable (IPPC, 2003). This document will be regularly updated to incorporate newly developed techniques. The document can be accessed at http://eippcb.jrc.es.

Nitrate Directive

The EU member states adopted the Nitrate Directive in 1991 to protect waters against pollution caused by nitrates from agricultural sources. This directive requires member states to designate nitrate vulnerable zones and to establish action plans for the minimization of agricultural nitrate leaching in these zones. Pollution of surface- and groundwater by excess nutrients from agriculture is a major cause of concern in Europe. This input far exceeds the uptake by crops and vegetation and poses a threat to surface- and groundwater quality. The nitrogen surplus in 1997 ranged from 24 kg/ ha in Portugal to 256 kg/ha in The Netherlands (Eurostat, 2001).

To address the above issue the Nitrate Directive defines actions related to agricultural nutrient management and application that are particularly relevant for nitrate leaching. These include measures such as periods of prohibition of fertilizer application, maximum yearly N-application per ha for animal manure, restrictions for application of manure on sloped or frozen soils, sufficient manure storage, crop rotation, buffer strips etc. The nitrate directive has a strong impact on swine production in concentration areas. For example in the Netherlands the directive has been implemented by the introduction of a minerals accounting system for farms. All livestock facilities have to keep record of their yearly input and output of N and P, and depending on the amount of own land have to register the mineral surpluses. Livestock producers with mineral surpluses have to transport animal manure to arable land of other farms or otherwise face levies on these surpluses. To enable farmers and authorities to keep track of the minerals on the farms, correct figures for the mineral contents of manures should be used. Therefore, samples from all manure transports originating from the particular farm have to be taken and analyzed.

NEC Directive

The 2001 Directive on National Emission Ceilings for certain atmospheric pollutants (the so-called NEC directive) requires member states of the EU to establish and report emission inventories and projections (up to 2010) for the four pollutants covered (sulphur dioxide (SO2), nitrogen oxides (NO_2), volatile organic compounds (VOC) and ammonia (NH3)) and to report these data yearly to the European Council and the European Environmental Agency. Additionally, states are obliged to draw up national programs to show how they are going to meet the national emission ceiling by 2010 at the latest. For livestock production in the Netherlands the NEC is especially important with regard to the requirement that ammonia emission, where livestock production contributes more than 90%, has to be significantly reduced. The 2000 level of 157 kton ammonia has to be reduced to 100 kton in 2010. The main approach to reach this target is the obligatory implementation of low emission housing systems in case of building or renewing animal housings.

Odor regulations

Odor nuisance from agriculture is caused by two main sources: odor from application of manure on the field and odor from livestock buildings. Different approaches can be distinguished to regulate odors (Mahin, 2001):

1. The use of specified setback distances between new or expanding livestock operations and sensitive receptors which are based only on the number and type of animals and the type of receptor (such as single home versus residential development / urban area).
2. Similar as indicated for 1, but including additional factors that influence odor emissions and odor dispersion, such as manure handling system, local terrain type, type of feed, type of ventilation system, etc.
3. The use of ambient air limits for individual compounds, such as hydrogen sulphide as used in certain states in the US and Canada.
4. Off site limits based on levels predicted by dispersion modeling and using the dynamic olfactometry approach.
5. General regulatory schemes/statements that prohibit off-site nuisance or annoyance conditions as determined by field inspectors.

In the Netherlands the first approach has been chosen. Since 1972 a regulation is in force to control odor emission from livestock buildings. The basis of this regulation can be summarized as follows, (Klarenbeek and Harreveld, 1995):

- Odor emissions from all livestock farms are calculated on basis of a table with conversion values. Within this table the odor emission for all species and categories of livestock is converted to a standard emission per animal, expressed in a unit that corresponds to the odor emission of one fattening pig .
- A distance chart gives the minimum distance between the farm, with a certain odor emission, and an odor sensitive object (e.g. a house).
- A division in level of sensitivity of the different objects. For instance another farm has a lower sensitivity than a house. Four different sensitivity categories are distinguished.

At the moment the Dutch Government develops new approaches. Targets for odor regulation are to limit odor annoyance to a maximum of 12% annoyed locations at the short term and no annoyed locations in the long term. Within the table with conversion values additional values have been included, e.g. for systems that proved to give low ammonia emissions, also lower conversion values are given for odor emissions. Recently an odor measurement program that started in 1997 has been completed to validate and modify the conversion factors in this regulatory scheme ((Mol and Ogink, 2002; Ogink and Koerkamp, 2001).

In Germany and Austria the second approach is used. Setback guidelines are being used. The potential odor emission is first assessed by the number of animals. Step two in the assessment is the evaluation of the system used, e.g. manure handling, ventilation system, type of feed, the topography of the site etc. The separation distances are fixed by graphs.
In Belgium and the UK the fourth approach is in use. In Belgium 'sniffing units' are determined. The sniffing unit is defined as the maximum distance from the odor source at which the odor can be observed. The sniffing units of an odor source are determined by on site measurements. On basis of the determined sniffing units the emission rates from the source are determined by

dispersion modeling. In the UK maximum levels of OU/m3 of air are set, based on emission measurements at the odor source and dispersion modeling.

In Denmark and Norway approach 5 is used. In Denmark for new livestock facilities a minimum distance should be maintained from urban areas. There is also regulation on the way the manure should be applied into the soil. In Norway an environmental impact assessment is required for large livestock facilities.

Measurement methods for odor and ammonia

Odor can be measured or characterized in different ways:

- By human sensory evaluation;
- By chemical evaluation;
- By electronic sensor evaluation

Sensory evaluation of odor

Odors from livestock buildings are usually a complex mixture of individual odorous compounds. This makes quantification of odor a lot more difficult than measuring for instance ammonia concentration in the air. At the moment the human nose is still the most reliable instrument to measure odor. The sensory observation of odor can be expressed in terms of quantity (concentration) and quality (pleasantness of the odor). Odor concentration is determined by the amount of odor units per unit of volume. One odor unit is defined as the amount of odor causing gases that when diluted in 1 m^3 of air just can be distinguished from clean air by 50% of the members of an odor panel. The definition of odor unit is rather complex, because it tries to quantify a physiological response on an odorous gas, in which different components can be present.

In Europe, odor measurements have been made for more than 20 years based on various methods, different panel selections, a variety of dilution systems (olfactometers) and different reference substances. A working group from the European Standardization Organization (CEN) has recently completed a new standard method EN 13725 to measure odor concentration by olfactometry (CEN, 2003). The quality criteria within this standard mainly address the following:

- Instrumental accuracy of the dilution equipment (dynamic olfactometer).
- Sensory accuracy of the selected panel.
- Overall quality criteria of the complete olfactometry system of each individual laboratory, i.e. regular testing of panels with reference substance n-butanol.

An odor sample is evaluated by a panel of at least 4 persons at 2 repetitions per person. Odor concentration in terms of odor units per m^3 of air (OU/ m^3) is determined as the geometric mean of the measured odor threshold values of the sample.

In recent years dynamic olfactometry is worldwide accepted as the standard method for determining odor concentrations in odor units. The main explanation for this is that dynamic olfactometry has the best potential for high accuracy and repeatability. The accuracy and repeatability of the measurements are improved by selecting panel members with similar odor sensitivity. For this selection a standard odorous gas, e.g. n-butanol, is used. In the new EN 13725 standard panel members are selected who have an odor detection threshold between 20 and 80 ppb. Standard errors in the determination of the odor concentration of a single odor

sample, according to the Dutch standard NVN 2820 that is almost similar to the new CEN standard, are in the range of 15 to 20% under repeatability conditions (Ogink and Klarenbeek, 1997).

Qualitative measurements of odor

Not only is the quantity of odor of importance with respect to nuisance, but the quality of the odor as well. Therefore methods have been developed to determine the (un)pleasantness of an odor as well. This is called the hedonic value of the odor. In Europe, the most accepted hedonic measuring system is based on the German VDI-guideline (VDI, 1994, 1992). Within this method odorous air is offered to a panel at increasing concentrations. All concentrations lie above the threshold value of the odor. Panel members have to characterize the odor at every concentration level on a scale between –4 (very unpleasant) to 4 (very pleasant). For unpleasant odors, generally, the unpleasantness increases at increasing concentration of the odor. Within the VDI method a linear relationship is assumed between the logarithm of the odor concentration and the hedonic value at that concentration. Little is known as yet about the accuracy and repeatability of the hedonic value measuring system. Further research and standardization within this area is needed and ongoing.

Chemical evaluation of odor

Odor from livestock production systems, generally, consists of a wide range of odorous compounds. This wide range of compounds is defined in this paper as the odor profile. This odor profile can be chemical and analytical characterized by determining which compounds are in this profile and at which concentrations. For chemical analysis of the odor profile three successive steps are essential: sampling and preconcentration of the odor, separation of components and identification of the separated components. The basic technique for separation of odorous compounds is gas chromatography. The best available technique for identification of volatile odorous compounds in combination with gas chromatography is mass spectrometry. This combination of separation and identification is also called GC-MS. With this method volatile compounds can not only be identified but quantified, as well. Until recently, high investment costs in combination with the complexity of the system and the experience needed to interpret the data have blocked a broad introduction of this system. During recent years, however, the costs of this system have been reduced. Modern systems have an extended build-in library of the different spectra of components. This makes interpretation of the data more easy and straightforward.

Electronic sensor evaluation

The concept of an electronic nose device originated from about two decades ago. The basic sensing elements are an array of non-specific chemosensors. Signal patterns from these sensors are related to the measured odors using a wide variety of methods. Electronic noses are attractive from the perspective that they enable continuous and in principle low-cost monitoring of odors. The main application area of commercial devices is quality control, especially in the food processing industry. Applications in livestock production have been explored on an experimental basis (Gallmann et al., 2003), but are far from implementation given the complex mixture of compounds in livestock odors.

Relationship between olfactometry and chemical-analytical methods

Olfactometry is a rather time-consuming method to determine odor concentration. Therefore, different research groups at different places in the world have tried to develop cheaper and more practical methods. Starting point of these alternative methods are that they should have a good relationship with olfactometry values. Until now the results are rather poor, mainly caused by the complex odor profile in livestock production. This odor profile is not easily characterized by just a few components. (Hobbs et al., 1995) distinguished 15 components in air from livestock buildings as the main components determining odor concentration. By determining these components in air samples taken from air above storage systems for pig manure, 75% of the variance between odor concentrations of these samples could be explained. New developments with regard to improved GC-MS techniques and the development of electronic noses may eventually link the analytical approach to sensory measurements.

Measuring methods for ammonia emissions from animal housings

In the Netherlands, ammonia emission factors expressed in kilogram's ammonia per day and per animal are assigned to all existing animal housing systems in the different animal categories. Based on these factors the total ammonia emission per farm is calculated that should exceed levels that are defined in the environmental license for production. Accurate validated emission factors are important both for producers and regulators and are based on measurements taken on farm locations according to a standard protocol. From the early 1990's on the ammonia emission of a broad range of housing systems have been measured.

Animal houses are in general, a well-defined source, the emission occurring from a confined space. But while in mechanically ventilated animal houses the inlets and outlets are normally well defined, this is not usually the case for naturally ventilated animal houses, because openings can act in some cases as inlet and in some other cases as outlet, depending on the weather conditions. The current protocol to measure ammonia emissions from animal houses is based on continuous measurements of the ventilation rate and the ammonia concentration in the outgoing air. The ammonia emission is then calculated as the product of the ventilation rate and the ammonia concentration leaving the animal house via the different outlets. For mechanically ventilated animal houses, the current protocol specifies the use of a NH3 to NO converter and a NOx analyzer to measure ammonia concentrations, and a fan wheel anemometer in the shaft to estimate the ventilation rate (Groenestein et al., 2001). For naturally ventilated animal houses, the determination of the ventilation rate is based on the mass balance approach (intern tracer gas ratio method): a tracer gas is introduced in the animal house at a constant rate (Qtracer), and the concentration of the tracer gas (Ctracer) is measured in the outgoing air (Mosquera et al., 2003).

The ratio between the (constant) tracer gas emission and the measured concentration is then used as an indicator of the ventilation rate in the animal house for the calculation of the ammonia emission (Q_{NH3}): $Q_{NH3} = \frac{Q_{tracer}}{C_{tracer}} \cdot C_{NH3}$

Because the frequency of measurements of ammonia concentrations and ventilation rates is high, the results obtained following this approach (continuous measurements of ventilation rates and concentrations) are usually precise and reliable for the investigated site. One advantage of using

this method is that it is possible to follow the emission processes. However, care should be taken on:

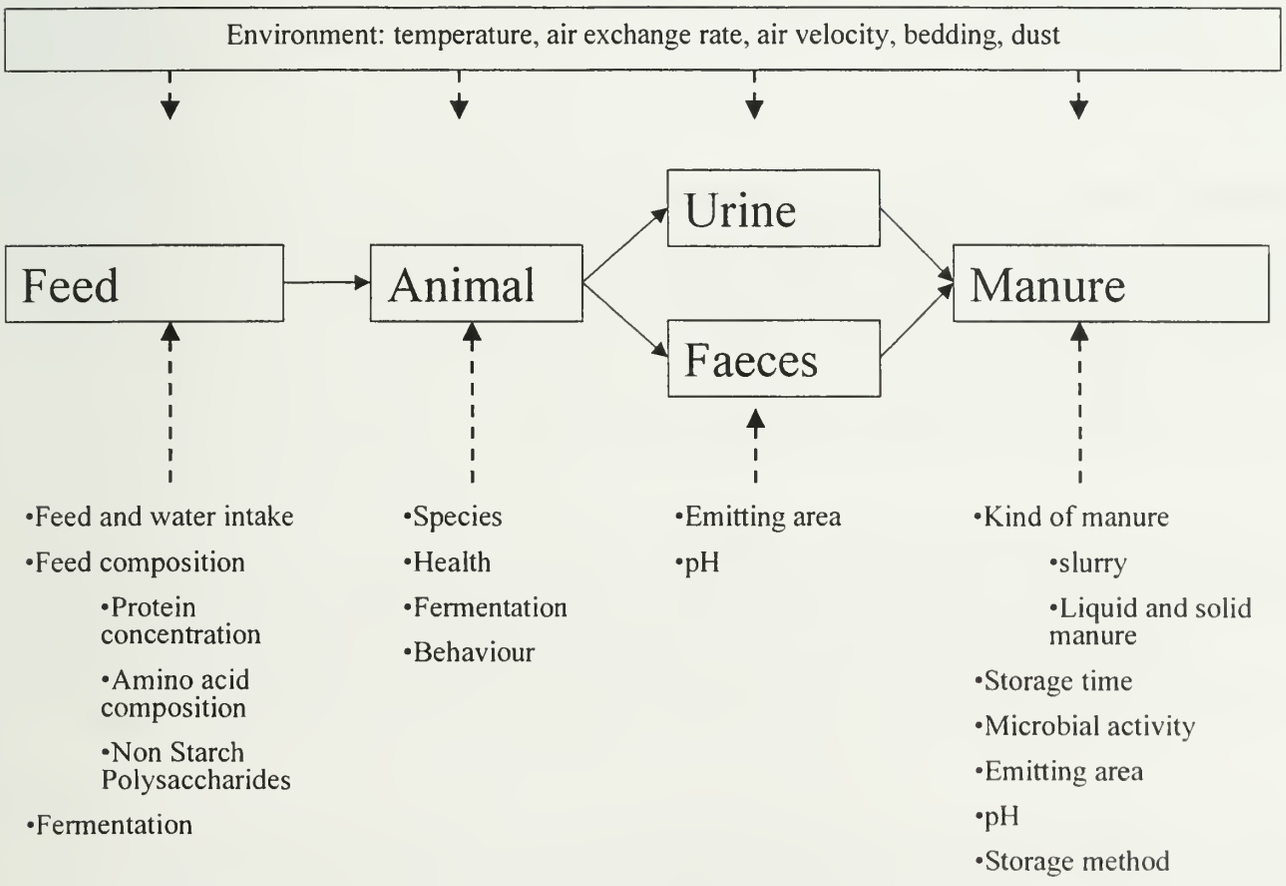
- Periodic calibration of the equipment by specialized personnel
- Heating and isolation of the sampling line, to avoid condensation problems, because ammonia rapidly dissolves in water,
- The anemometer should cover the total exhaust area (for mechanically ventilated houses)

In addition, using the mass balance approach for ammonia and the tracer gas for naturally ventilated animal houses requires the following assumptions to be fulfilled:

- The tracer gas should be injected in a way that mimics the ammonia emission sources in the animal house (i.e. tracer gas injected close to ammonia sources)
- The dispersion of both ammonia and the tracer gas should be similar, which implies the assumption of good mixing of both gases in the animal house, and that the residence time for both gases is long enough to allow them to mix properly
- The tracer gas should be easy detectable with the used equipment

Factors that affect odor emission in livestock production

Different factors affect the forming and emission of odorous components in livestock production. In the scheme below the main influencing factors are shown. The main factors are discussed.



Feed and water

Feed is the source material for almost all odorous compounds in animal houses. Not much research has been done yet on the relationship between feed and odor emissions. In theory,

however, this seems a very promising route to tackle high odor emissions from animal houses. According to (Spoelstra, 1980) the inhibition of methanogenesis in wastes is an important cause of the accumulation of volatile odorous compounds in manure. When methanogenesis is not inhibited these odorous compounds will be broken down to CH4 and CO2. Inhibiting factors are according to the same author:

- low temperature of the manure;
- overloading of the system, causing high concentrations of inhibiting components like hydrogen and ammonia;
- toxic effects of heavy metals.

The last two inhibiting factors can be influenced by dietary manipulation, and this might be an option for future research on reducing odor emissions.

Hobbs et al. (1997b) have confirmed the hypothesis of reducing odors by reducing the dietary crude protein. However, they proved that also other components are of importance. In their study the home- grown cereal based diet caused higher odor emissions than the least cost formulated diet, based on fish meal and soya, at the same protein content of the diets.

Animal

Animal behavior in relation to odor emission is especially important for pigs. Pigs, generally, make a spatial separation between the lying and excreting locations. Different studies have shown that when this separation is not clear and the solid pen floor is fouled with feces urine, odor emission may increase considerably. Especially in the summer at high ambient temperatures pen fouling is difficult to prevent in partially slatted pens for fattening pigs (Aarnink et al., 2000).

Urine and feces

Some odorous compounds are formed by the fast process of enzymatic hydrolysis. Examples are the reduction of sulphate to hydrogen sulphide, the hydrolysis of glucuronides to phenols and the hydrolysis of hypuric acid to benzoic acid (Spoelstra, 1980). All these components are present in urine. The emission of components from urine is linearly related to the emitting area in animal houses as long as the source in urine is not limiting. For well soluble components in the manure, like ammonia, indeed a linear relationship was found (Aarnink, 1997). For badly soluble components this relationship is not valid. Then, the velocity of formation and diffusion to the surface mainly determines emission.

The emission of almost all odorous compounds is influenced by the pH. The pH determines the equilibrium between the ionized and non-ionized form of the component. When the equilibrium is shifted toward the non-ionized form the emission will increase. Within an alkaline environment, especially, the alkaline components will emit (e.g. ammonia), while in an acid environment, especially, the acid components will emit (e.g. volatile fatty acids).

Manure

With respect to the kind of manure it seems important whether the urine and feces are stored as slurry or whether they are stored separately. Quantitatively little is known yet about the effect of manure separation on odor emission. Pain and Bonazzi (1993) reported lower emissions from

straw manure than from slurry. Straw can bind odorous compounds and a thick layer of straw also reduces the air exchange between the manure and the air.

Most odorous compounds in animal houses are formed from anaerobic digestion of manure during storage. Especially, the breakdown of protein and crude fiber may produce odorous compounds (Pain and Bonazzi, 1993). According to Spoelstra (1980) odorous compounds are mainly formed when the different processes in this breakdown are not in balance. Within a balanced situation the volatile odorous compounds will be converted into methane and carbon dioxide. Research by Hobbs et al. (1997a) supports the hypothesis of Spoelstra. They found a negative relationship between methane and odor emissions.

For the emitting area and the pH the same is valid for manure as for urine and feces. Klarenbeek et al. (1982) found a positive relationship between the manure surface in the pig house and the odor emission. They also found a reduction in odor emission of 39% when the manure was regularly flushed from the pig house with aerated manure.

Ambient factors

Temperature of the manure seems to be a very significant factor for odor emissions. Klarenbeek et al. (1982) found lower odor emissions of 80% in the winter when compared to the summer. Also Verdoes and Ogink (1997) found higher odor emissions in the summer season than in the winter season for all categories of pigs. Donham et al. (1985) found significant lower odor emissions at temperatures below 18oC. Oldenburg (1989) found correlation coefficients varying from 0.40 – 0.84 between the seasonal temperature changes and odor emission. Different researchers also found positive correlations between air exchange rate and odor emission (Oldenburg, 1989; Ogink et al., 1997). A higher air exchange rate increases the concentration difference between the manure and the air, thereby increasing emissions. Also increased air velocities above the emitting surface will increase the release of volatile compounds.

About the effect of straw on odor emissions little is known yet. Straw may have different effects: (1) it increases the emitting area; (2) it absorbs volatile compounds; (3) it reduces the air exchange between the manure and the air. Depending on which factor has the strongest effect in a certain situation odor emission will decrease or increase when using straw.

Odor reducing measures and techniques

Some techniques are available at the moment to reduce odor emission from livestock production units. These techniques can be subdivided as follows:

- Techniques preventing the release of odor from the manure (manure treatment techniques).
- Techniques preventing odorous air being emitted from animal houses and manure stores (air treatment techniques).
- Preventing nuisance from odorous air by dilution.

Manure treatment techniques

Aeration of manure will oxidize volatile (odorous) components to especially carbon dioxide and water. In the 1980's in the Netherlands aerating systems were installed in manure storages outside animal houses. The aerated manure was used to flush the fresh manure from the animal

house as well, thereby reducing the emission from the building as well. Aerated manure has a low odor emission at surface application of the manure as well. Drawbacks are the high-energy costs and the loss of nitrogen (by nitrification and de-nitrification nitrogen is lost as N2). Because of the high costs this approach is not applied in livestock facilities in Europe.

Anaerobic digestion of manure converts most of the odorous compounds in methane and carbon dioxide, causing less odor emission (Jongebreur and Schaefer, 1980; Powers et al., 1995) main disadvantage is the production of ammonia and hydrogen sulphide. The digested manure, therefore, is less suitable for flushing the fresh manure from animal houses.

Adding chemical components to the manure may reduce odor emission. Changing the pH of the manure to levels below 4 or to levels above 9.5 will stop biological activity and thereby stop the production of odorous compounds. Other chemical methods to reduce odor emission is the binding, elimination or masking of odorous compounds (Ritter, 1989). Additives are not used in practice.

Air treatment techniques

It is known for a long time that biofilters consisting of materials like compost, peat, bark or mixtures of these materials can effectively clean the air from odorous compounds. These compounds are removed by a combination of adsorption, absorption and biological breakdown. Important parameters are the retention time of the air inside the filter and the humidity of the filter. In the Netherlands biofilters are normally not used in livestock production because of a lack of reliability of the filter (risks of leakage shortcuts), and the risk of high ammonia concentrations in the inlet air of the filter that eventually may lead to contamination of the filter and a breakdown of its microbial functioning.

The risk of contamination by ammonia is being eliminated in air scrubbers in which odorous air is intensively contacted with the washing liquid that is recycled. The recycling liquid is frequently discharged to remove the accumulated components and thus contamination is avoided. Two types of air scrubbers can be distinguished: bio scrubbers and chemical scrubbers. The bio scrubber is characterized by the biological activity within the filter. Bacterial mass is developed on the filling material of the filter. These microorganisms are responsible for the breakdown of the organic compounds within the air. The filling material is important to reach a large area per unit of volume without increasing the flow resistance to undesirable levels (Hartung et al., 2001). In a chemical scrubber compounds are bound chemically and by that way removed from the air. Because air from animal houses consists of a lot of different chemical compounds, chemical scrubbers are less suitable for reducing odor emissions. Ogink and Koerkamp (2001) reported a reduction of 29% when using an acid scrubber in a house for growing-finishing pigs. For bioscrubbers different filling materials are available. Most are made of plastic. The main function is that the area per unit of volume is increased without causing a large pressure fall across the filter. Odor reduction efficiencies of varying types of bioscrubbers at pig facilities in practical conditions ranged between 40 and 50% on average (Mol and Ogink, 2002). From other research under experimental conditions it is known that odor removal by bioscrubbers can be more efficient up to reduction percentages of 60-70%. However it has to be realized that bioscrubbers in the Netherlands are primarily dimensioned for the removal of ammonia and not for odor.

Dilution of odorous air

Odorous compounds are generally not directly detrimental for the environment. Therefore the odor problem is especially a concentration problem. Dilution of odorous air before it can cause nuisance for the people living in the vicinity of the farm is therefore an acceptable method to reduce the odor problem. High trees around the farm or high extended ventilation shafts for removal of the odorous air are effective methods to dilute the odorous air.

Low emitting swine housing systems

To abate ammonia deposition in the Netherlands, governmental policies and measures have been developed that are aimed at reduction of emission of ammonia, including:

- Covering of outside slurry storage (1985, mandatory)
- Restrictions to slurry application during autumn and winter, and the obligatory use of low emission techniques (injection) in application of manure (1990, mandatory)
- Promoting the introduction of low emitting animal housing, Green Label covenant (1995, voluntary)
- Transition towards low emitting swine and poultry houses (2002-2008, mandatory)

Key element in the ammonia abatement policy is the transition towards low housing systems. Maximum emission levels per animal have been defined for the main animal categories that have to be fulfilled by 2008. For swine producers this means that current emission levels of fattening pigs in conventional housings with partially slatted floors and slurry storage under slats have to be reduced from yearly 2.5 kg ammonia per pig to a maximum of 1.2 kg ammonia. Similar reductions have to be reached for sows and piglets.

From the 1990's on a wide variety of new housing systems have been developed. The main principles used here are:

- Reduction of the emitting slurry surface by a specific configuration of the slurry pit (Figure 2);
- Cooling of the upper layer of stored slurry in the barn thus creating an air-boundary layer that minimizes conversion processes and air exchange between the boundary layer and air in the house (Figure 3);
- Implementation of air scrubbers (chemical scrubbers and bioscrubbers).

The minimum extra yearly costs for investments in low emitting systems compared to the conventional housings are estimated at 3-5 euro per pig place depending on the housing type. Currently, approximately 30% of the fattening pigs in the Netherlands are housed in these low-emitting systems.

Perspectives for managing emission in swine production in Europe

During the last decade growing public concern for the protection of the environment and the quality of life has led to new legislation by the European Union with clear targets and time schedules to reduce environmental pollution. For livestock production and swine production in particular the directives that aim to reduce the damaging effects of ammonia deposition (NEC directive), to improve the water quality (Nitrate directive), and the local environment around industries (IPPC directive) are of great importance. Especially in the regions with high animal

densities, like in the Netherlands (Figure 1), compliance to these directives is a challenge that requires a strict control of emissions to the air (ammonia, odor, greenhouse gases) and emissions to soils and water through manure application (N and P minerals, heavy metals). Over the last decade a number of technical measures have been developed to reduce these emissions. Significant progress has been made in developing direct injection methods for manure application and low emitting housing systems. So far farmers in these regions have managed to balance the extra investment costs by other factors like scale of operation, favorable logistics, efficient management, and product quality. Yet still considerable efforts have to be made to reach the environmental targets for 2010 and further. In the Netherlands experiences from the last years has demonstrated that these targets can be reached only if the following socio-economic and technical factors are considered by the involved parties:

- Understanding and agreement on the environmental impact (including nuisance) of emissions by both authorities and livestock producers are essential for an effective strategy based on well motivated parties.
- Improvements in both housing systems and management practices should be utilized. So far regulations have put main emphasis on housing systems as an easily verifiable element in licensing. However, monitoring of farm emissions with identical housing systems indicate large differences as a result of different management practices (feed composition, pen hygiene, ventilation management). These variations provide a basis for improving management. Means have to be developed that credit farmers for good management practices that can be monitored.
- On-farm monitoring of emissions through direct and indirect parameters enables producers to tune their management toward low emissions and utilize their innovative abilities. There is a need for low-cost monitoring devices to support management.
- Integrated approaches are required that consider both environmental, ecological, animal welfare and economic factors. Pilots of integrated approaches on farm level have been worked out that demonstrate the technical possibilities (Ogink et al., 2001; Willers et al., 2000) but that need further development for implementation in practice.

REFERENCES

Aarnink, A. J. A. 1997. Ammonia emission from houses for growing pigs as affected by pen design, indoor climate and behaviour. Ph.D. thesis Agricultural University Wageningen, 175 pp.

Aarnink, A. J. A., J. W. Schrama, R. J. E. Verheijen, and J. Stefanowska. 2000. Effect of ambient temperature on pen fouling by pigs. Proceedings of the Xth International Congress on Animal Hygiene, Vol. 2, Eds. M.J.M. Tielen and M.Th. Voets, ADDIX Wijk bij Duurstede, p. 933-937.

Breemen, N. van, et al. 1982. Soil acidification from atmospheric ammonium sulphate in forest canopy throughfall. Nature 1982, 299: 548-550.

CEN. 2003. Air quality - determination of odour concentration by dynamic olfactometry EN 13725. European Committee for Standardization, Brussels.

Donham, K. J., J. Yeggy, and R. R. Dague. 1985. Chemical and physical parameters of liquid manure from swine confinement facilities: Health implications for workers, swine and the environment. Agricultural Wastes 14, 97-113.

Eurostat. 2001. Eurostat: Agriculture and fisheries, yearbook 2001. European Commission, Brussels.

Gallmann, E., E. Hartung, G. Brose, and T. Jungbluth. 2003. Determination of the dynamics of the odour release from a pighouse using an electronic odour sensor. In: 2nd IWA International Conference on Odours and VOCS, Singapore

Groenestein, C. M., J. M. G. Hol, H. M. Vermeer, L. A. den Hartog, and J. H. M. Metz. 2001. Ammonia emission from individual- and group-housing systems for sows. Neth. J. Agric. Sci. 49: 313-322.

Hartung, E., M. Martinec, and T. Jungbluth. 2001. Biofilters - the influence of different filter material and different operating conditions on the reduction efficiency. Water Science and Technology 43: 253-260.

Hobbs, P., B. F. Pain, and T. H. Misselbrook. 1995. Odorous compounds and their emission rates from livestock wastes. In: Proceedings of the International Livestock Odor Conference '95, New Knowledge in Livestock Odor Solutions, p. 11-15, Iowa State University, Ames.

Hobbs, P. J., T. H. Misselbrook, and B. F. Pain. 1997a. Assessment of odours from livestock wastes by photoionization detector, and electronic nose, olfactometry and gas-chromatography, mass spectometry. J. Agric. Engng Res.60: 137-144.

Hobbs, P. J., B. F. Pain, R. M. Kay, and P. A. Lee. 1997b. Control of odours by dietary manipulation. In: J.A.M. Voermans and G.J. Monteny, Proceedings of the International Symposium on Ammonia and Odour Control from Animal Production Facilities, p. 267-269 Proefstation voor de Varkenshouderij, Rosmalen.

IPPC, 2003. Reference document on best available techniques for intensive rearing of poultry and pigs.European Commission, Brussels

Jongebreur, A. A., and J. Schaefer. 1980. Emissies uit intensieve veehouderijbedrijven. Handboek Milieubeheer, Deel II, Zorg voor luchtkwaliteit, Vermande en Zonen IJmuiden.

Klarenbeek, J. V., and A. v. Harreveld. 1995. On the regulations, measurement and abatement of odours emanating from livestock housing in the netherlands. In: International Livestock Odour Conference 1995, Ames, Iowa, US. p 16-21.

Klarenbeek, J. V., A. A. Jongebreur, and S. C. C. Buimer. 1982. Geuremissies bij mestvarkensstallen. rapport 48 IMAG-Wageningen.

Mahin. 2001. In: 1st IWA International Conference on Odour and VOC's: Measurement, Regulation and Control Techniques, The University of NSW, Australia

Mol, G., and N. W. M. Ogink. 2002. Geuremissies uit de veehouderij ii overzichtsrapportage 2000-2002, IMAG.

Mosquera, J., G. J. Monteny, and J. W. Erisman. 2003. Overview and assessment of techniques to measure ammonia emissions from animal houses: The case of the netherlands. In: Congress: National Atmosheric Deposition Program 2003, Washington

Ogink, N. W. M., A. J. A. Aarnink, A. J. Hoofs, and I. Vermeij. 2001. Sustainable pig production with the hercules-system. In: Tagung Bau, Technik und Umwelt in der landwirtschaftlichen Nutztierhaltung 2001, Hohenheim. p 326-331.

Ogink, N. W. M., C. t. Beek, and J. V. Klarenbeek. 1997. Odor emission from traditional and low-emitting swine housing systems: Emission levels and their accuracy. Paper No. 974036, ASAE Annual International Meeting, ASAE, St. Joseph Mich.

Ogink, N. W. M., and J. V. Klarenbeek. 1997. Evaluation of a standard sampling method for determination of odour emission from animal housing systems and calibration of the dutch pig odour unit into standardised odour units. In: J.A.M. Voermans and G.J. Monteny, Proceedings of the International Symposium on Ammonia and Odour Control from Animal Production Facilities, p. 231-238, NVTL Rosmalen, The Netherlands.

Ogink, N. W. M., and P. W. G. G. Koerkamp. 2001. Comparison of odour emissions from animal housing systems with low ammonia emissions. Water Science: 245-252.

Oldenburg, J. 1989. Geruchs- und ammoniak-emissionen aus der tierhaltung. KTBL-Schrift 333, Munster-Hiltrup, 158 pp.

Pain, B. F., and G. Bonazzi. 1993. Odours from livestock production. Report European Conference Mantua Italy, 79 pp.

Powers, W. J., A. C. Wilkie, and H. H. v. Horn. 1995. Effect of anaerobic digestion and commercial additives on odors from liquid dairy manure. In: Proceedings of the International Livestock Odor Conference '95, New Knowledge in Livestock Odor Solutions, p. 44-49, Iowa State University, Ames.

Ritter, W. F. 1989. Odour control of livestock wastes: State-of-the-art in north america. J. Agric. Engng Res. 42, p. 51-62.

Spoelstra, S. F. 1980. Origing of objectionable odorous components in piggery wastes and the possibility of applying indicator components for studying odour development. Agric. Environ. 5: 241-260.

Tamminga, S. 1992. Gaseous pollutants produced by farm animal enterprices. In: C. Phillips and D. Piggins, Farm Animals and the Environment. C.A.B. International, p. 345-357.

VDI, 1992. VDI 3882 blatt 1 olfactometry: Determination of odour intensity. VDI, Düsseldorf.

VDI, 1994. VDI 3882 blatt 1 olfactometry - Determination of hedonic odour tone. VDI, Düsseldorf.

Verdoes, N., and N. W. M. Ogink. 1997. Odour emission from pig houses with low ammonia emission. In: J.A.M. Voermans and G.J. Monteny, Proceedings of the International Symposium on Ammonia and Odour Control from Animal Production Facilities, p. 317-252, Proefstation voor de Varkenshouderij, Rosmalen.

Willers, H. C., P. Hobbs, and N. W. M. Ogink. 2000. Odour release from the hercules evapo scrubber. In: AgEng 2000, Warwick

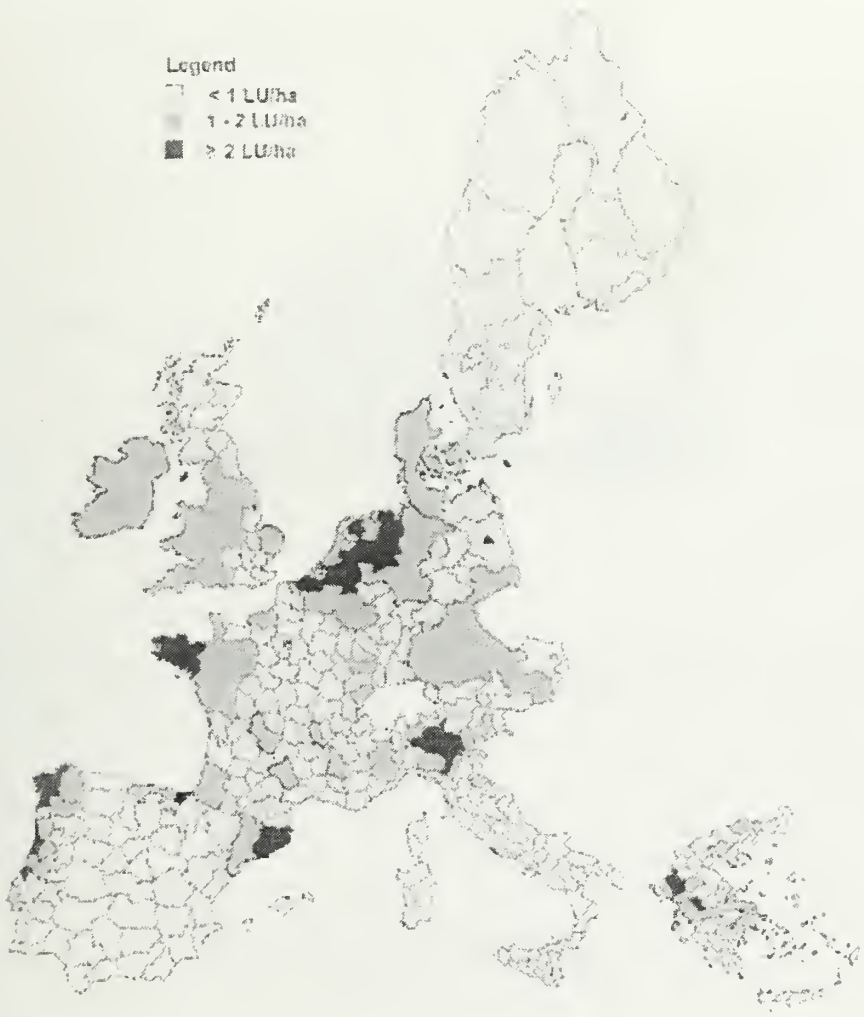


Figure 1. Animal density in the European Union in number of livestock units (500 kg LW) per hectare of utilised area (IPPC, 2003)

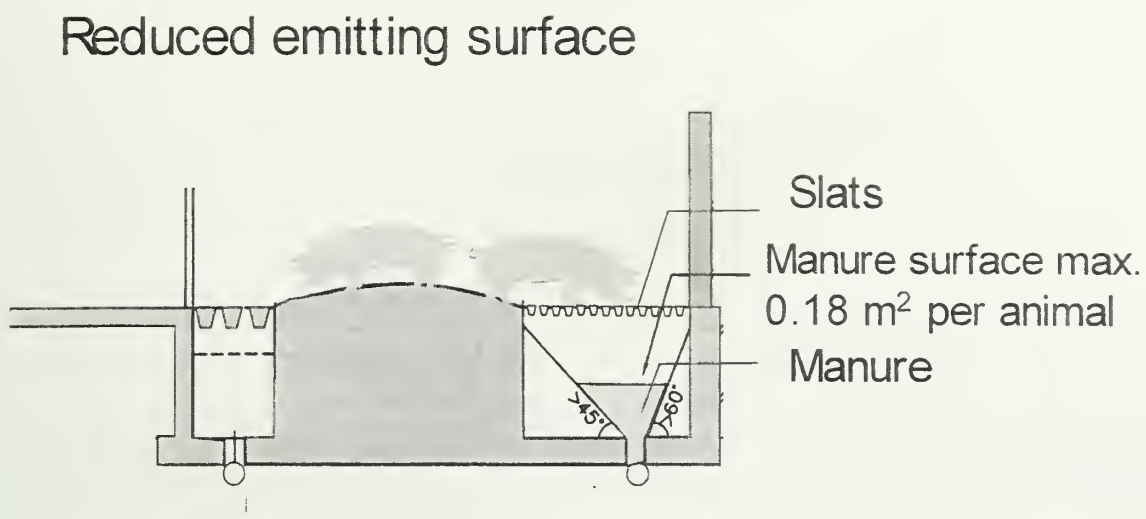


Figure 2. Schematic depiction of the housing system with a reduced emitting surface in the manure pit underneath the slatted floor.

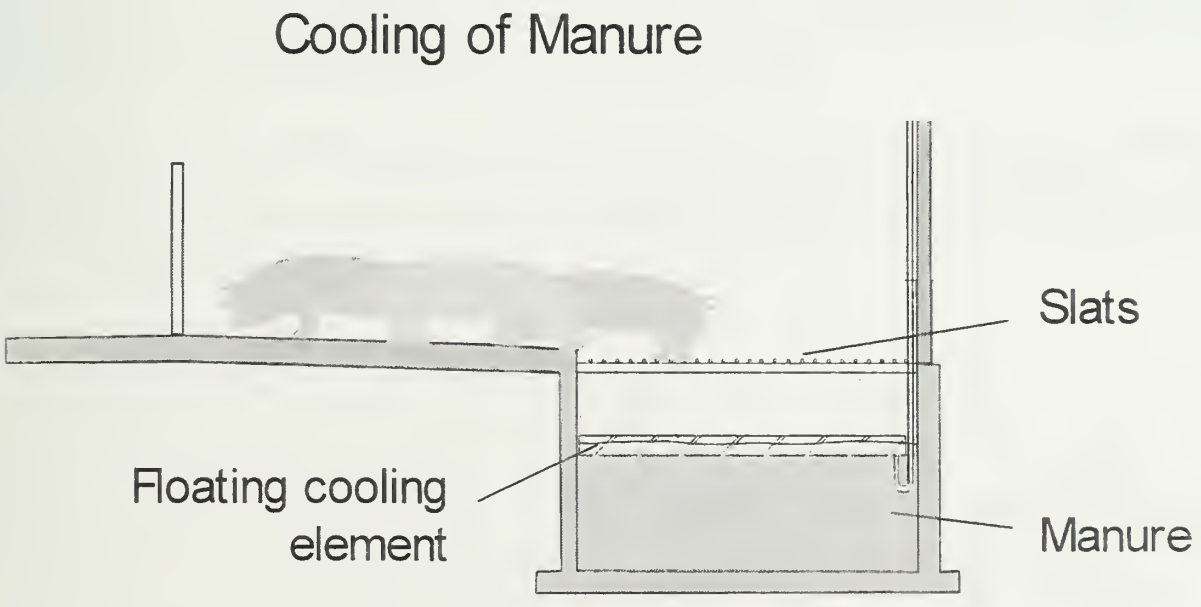


Figure 3. Schematic depiction of the housing system with cooling of the manure in the manure pit underneath the slatted floor.

THE SOLUTION TO POLLUTION ...IS ...

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INTRODUCTION

The mythical Ag. Engineer Hercules devised the solution to pollution some 4000 years ago, but in the last 40 years his formula became obsolete by the accumulation of unprecedented quantities of wastes causing the worst ever degradation of our natural environment. Fortuitously, the greatest progress in advancing the solution to pollution has been made in the last four decades, as well. So, as the legendary English novelist Dickens could put it, ***the last 40 years have been the worst and the best of times for the environment.***

During the last 40 years, the livestock industry experienced an exponential growth resulting in integrated large intensive animal farming units that created the need for laws and regulations to control animal waste pollution and minimize the environmental impact of the associated malodors. Urbanization with recent strong trends towards residential developments in rural areas has exacerbated the odor nuisance problem from animal production. Pollution from pig, cattle, and poultry farms has become one of the most challenging environmental problems. The environmental problems includes the generation of nuisance odors, the release of ammonia and other noxious gases to the atmosphere, the under-utilization of excess nitrogen and phosphorus, the improper use of persistent chemicals, the potential of zoonotic diseases, etc. These problems have led to the characterization of manure as a worthless waste.

The paper will trace the impact of Man and animals on the environment for the last 4000 years in general terms, and, more specifically, developments of the last 40 years in combating environmental pollution problems from the livestock industry, before concluding that the solution to pollution ... is...

Animals and Man [female and male]

Sheep and pigs were one of the first animals to be domesticated by Man. From the beginning of time, sheep and pigs were part of human settlements where they could be protected from their many predators. When I went to China in 1978 as a member of a UN technical mission, I saw pigs living within the household compounds of most of the rural homes. Note that the Chinese character for "home" or "family" is derived from the

word for pig covered by a roof, as is illustrated in the pictogram[1].

Man: from Hunter to Technologist

In the beginning, Man was a **hunter** competing with the wolf for sheep; this caused no ecological imbalance. But when Man confined sheep into protected enclosures, Man did create ecological problems for two main reasons: it deprived wolves of their free access to sheep, thus the number of sheep grew, and the human population followed suit since Man had more leisure time, which Man spent with his spouse resulting in a population explosion. So, Man was forced to become a **nomad** in order to access additional resources for his animals.

Then came the revolutionary idea of cultivating grains and crops: Man became a **farmer**, which allowed him to stay in the same place to get his food, and to feed the excess to his sheep and pigs, which gave him even more time, which Man used to increase his population to levels that could no longer be supported by the natural resources under his control. That is when Man became a **warrior** so that Man could get what he could not produce himself from others who were not as advanced in the art of war.

It took many millennia for the transformations of Man from a hunter in the wild savannahs of Africa to an agronomist in the mild plateaus of Mesopotamia [*within the rivers Euphrates and Tigris; today's Iraq*] to a nomad in the steppes of Asia [*crossing into the Americas through Alaska*] to a warrior in resource-deprived Europe [*WW I and WW II*], but the transformation of Man to a powerful **technologist took only decades**. Furthermore, what is most foreboding is that since 1989 [*after the fall of the last warrior, the Soviet Union, the globalization of the Internet as an uncensored supply of information, etc*], technology is accessible by every Man, properly educated or not, responsible or not! Thus, we are at a dangerous juncture because we can no longer avoid the consequences of the misuse of technology to inflict unbearable damages to our environment.

One of the biggest benefits that technology brought was the Green Revolution of the 1960s. I saw first-hand the benefits of the Green Revolution in 1966 when I was working in Punjab, in the rich plateaus of the Indus River basins, a region that served as the traditional breadbasket of the Indian subcontinent since the time of Alexander the Great, but soil fertility had suffered from overuse and abuse. These fields became highly productive again through the use of new crossbreeds for wheat and rice, machinery for efficient tilling and harvesting, timely irrigation, fertilization, university education training, etc., resulting in saving hundreds of millions of people from starvation in the Asian subcontinent. A side effect, of course, has been population explosion, a problem that continues to plague the world. India is scheduled to surpass China as the most populous country!

In the USA and the Americas, the Green Revolution resulted in the creation of huge grain surpluses. These enormous grain quantities were used to stimulate an exponential global growth in the raising of pigs, poultry, cattle, and other animals in the 1970s. The consequences were water and air pollution problems on top of soil erosion, soil degradation from excessive

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[1] Composed from drawings scanned from the book "***Fun with Chinese Characters***". 1980. Federal Publications. Singapore

irrigation, contamination of our soils from excess use of fertilizers, of manures, of chemicals, and the list goes on and on.

Technology Implications

During the **last 40 years**, Man is spending more than one hundred times more energy than the farmer of **4000 years ago**, but Man today spends only a tiny fraction of that huge amount of energy on food production. Man uses the limited resources of consumable energy to acquire faster transportation, including **extraterrestrial travel** into the limitless Space. Man the "***Technologist***" is evolving into a position of exerting an environmental impact beyond the boundaries of Earth. One of the most dramatic effects of the space explorations since the 1960s has been the realization that the Earth's biosphere is a very thin and limited layer with finite capacity to absorb and assimilate natural waste, and no capacity to assimilate many of the products that Man is synthesizing.

Emissions of heat-trapping greenhouse gases from the smokestacks of the industrialized countries and from countries that are now gearing up to become industrialized *[like India, China, Brazil, etc*], and ammonia production [*the pig industry in the European Union*[2] *alone is releasing some 800,000,000 lbs of ammonia to the atmosphere per year*], plus other noxious gases from the livestock industry of the world are causing serious ecological disruptions that affect both our health, our climate, our natural resources, and even our future survival. At this stage, I would suggest that instead of me listing all the global consequences of our actions over the last decades I would refer you to the webpage of the United Nations Environment Programme [UNEP][3] for details, statistics, and general concepts.

> ***"The harnessing of technology to maintain our economic health and also to protect our ecological resources and sustain development for the generations to come is now the challenge of the 21st century."***
>
> United Nations
> Environment Programme and World Bank

It is no longer ECONOMY at the expense of ECOLOGY, but for a long time it was so, and I am afraid whenever we go into recessions, [*as we are bound to do often because of the cyclical nature of economics*], politicians will revert back to their old habits of only serving the selfish short-term interests of the economy, unless the scientific community challenges them and re-convinces politicians to follow a balanced course of economic and environmental policies!

The Chemistry Question

A few years ago I had the distinct pleasure of listening to a talk by Nobel Laureate, fellow professor at The Ohio State University, Dr. Kenneth Wilson[4], and I was fascinated by his argument that one of the greatest challenges and the reasons for the need to develop even more powerful supercomputers than the current ones are that millions, if not billions, more chemical

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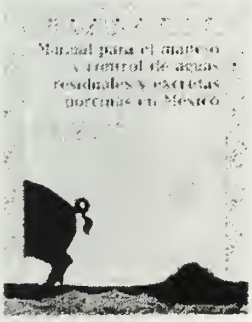
2 Knight V. 2003. *EU Pig's Stink: Ammonia.* The Wall Street Journal Europe. 2 Sept 2003.

3 www.unep.org United Nations Environment Programme, Nairobi, Kenya

4 K G Wilson. Professor of Physics, The Ohio State University, Columbus, OH. Wilson.9@osu.edu . [He is advocating s*omething like 10^8 increase in computing power; keep in mind, he was talking not about your and my PC, but increase over the computing power of the 5 Supercomputers, one of which was housed in a building of its own on the OSU campus*]

compounds could be formulated than the millions developed so far. A lot of these chemicals are going to be antibiotics, or drugs, or pesticides that will be used in the livestock industry. As impressed as I was with the clarity and originality of the thinking of this renowned physicist, my thoughts jumped instantly to the question: "***Who is going to tell Nature how to assimilate these new products into the fragile environment of our planet***?"

I recall the same dilemma that I had faced two decades earlier when I had the notable honor of being one of the technical advisers to the commission chaired by the then Col. John Glenn [*the first man to circle the earth in 1960, a prominent US Senator thereafter, and, in 1998, the oldest (75 years) man to go back into space, and thus had the unique advantage to see from up above both the beauty of the biodiversity of the Earth but also the intervening environmental wounds she was suffering*]. The commission was appointed soon after the landing of Neil Armstrong on the Moon **20 July 1969.** It was to formulate an environmental protection agency for the State of Ohio. Along with the panel members of the commission, I listened for days to stereotype testimonies from industrial representatives arguing that their industry could not possibly afford environmental restrictions [*industry survived environmental standards and even thrived, as we all know*], lamenting the fact the industries did not have the proper expertise to treat the wastes in an environmentally acceptable manner, and urging that the public sector take up the challenge and the funding of pollution management programs.



When my turn came to comment at the end of the hearings, I had the temerity to challenge the notion that the manufacturers, who were fiercely guarding the secrets of the manufacturing of their products, would not have the necessary expertise to make their products less damaging to the atmosphere. On the contrary, I argued that they would be best qualified to develop the means to assimilate those products in the environment, because they had secret proprietary knowledge on their products that was not accessible by the public sector. I argued the same thing for the pig farmers in Malaysia[5] and in Mexico[6] where I worked for several years, urging the pig industry in those countries to assume the responsibility to solve its own problems rather than let bureaucrats and outsiders dictate non-practical compliance schedules and expensive solutions that are more suited to factories and cities than farms.

Plastics were in the 1960's what the dot.com industry was in the 1990's. Both of them were bubbles that burst after a decade. Both of them transformed our way of life and work, forever and ever! Amen!
Eliseo

Going back to the Ohio EPA commission, I gave the example of the huge plastics industry that had blossomed in the Cleveland industrial hub of northeast Ohio. Thanks to preposterously low prices for oil in the 1960s, industrial chemists were let loose to develop plastics from crude oil extracted from the beds of the ancient rivers Euphrates and Tigris of Mesopotamia [*the historical*

5 Taiganides, et al 1988. ***Pig farming in Malaysia***. FAO, United Nations, Rome. 200 pp

6 Taiganides, et al, 1996. ***Manual para el manejo y control de aguas residuales y excretas porcinas en México***. Council of Mexican Pork producers [CMP], National University of Mexico [UNAM], 141 pp.

region where Man first discovered the solution to pollution, as we will see soon]. Cheap plastic bags, toys, etc, flooded the globe, and filled our sanitary landfills. When the oil prices skyrocketed because of the oil embargo in the 1970's, the industry chemists, who a decade earlier maintained they did not know how to make recyclable plastics, lo and behold, developed economic methods to recycle and re-use discarded plastics that had littered the Earth. Today, throughout Europe plastics are collected religiously and are recycled, and in Taiwan the use of plastic bags and plastic boxes in grocery stores and food outlets has been banned.

By the way, 40 years ago, the chemists in the paper industry claimed that paper could only be made from **virgin pulp,** which meant the cutting down of eons-old trees, but, as we all know, paper manufactured from recycled waste paper is the main source of paper in many parts of the world, today! Most of the paper plants I visited in Asia and the Americas use tons of waste paper shipped from the United States to make high quality paper products, which saves much space in our sanitary landfills and many of our tree resources!

HERCULES PRINCIPLE

Once upon a time, 4000 years before now [bn], Augeios moved to fertile Mesopotamia where crop farming had been invented. He had the avant-garde idea that made him a King among the farmers of the region who were growing wheat [*more profitable cash crops like* ***corn, potato, tomato, rubber, cocaine*** *that the indigenous peoples of the Americas had pioneered were not discovered until thousands of years later*]. Augeios confined thousands of cattle in stables. This was an innovation. The Augean stables became famous in all of world. Years passed without the King looking beyond the income ledgers from his stables that were of such high volume as to fund adequately the war with the peoples of the Levant! Things were going well until his neighbors, most of whom were cantankerous shepherds who had retired to hamlets surrounding the palace, lodged vociferous objections to the smell from the stables. [*The gerontic shepherds had become allergic to animal odors*]!

King Augeios investigated himself the stables and was shocked by the sight of mounds of manure that had not been cleared for years and the nauseating **stench** emanating from them. Augeios ordered his men to solve the problem that same day, or get rid of the animals! [*It is most interesting that odors are the most common criterion lay people use to define pollution, be it from animals or factories or sewage plants, and the immediate response is to obliterate the source of the problem, rather than solve the resulting problem, as we saw the young hippies do in the late 1960s demanding that pollutive factories be closed and that the "****gerontocracy establishment****" abdicate; the latter prevailed through the formation of the council of environmental advisers in the White House, the Environmental Protection Agency, among other receptive acts such as stopping the war in Vietnam*].

The King's men quickly contacted the Mount Olympus universal gods, who sent Hercules, their most qualified Ag Extension Engineer having solved 12 other impossible tasks. Hercules, the brawny son of thunder-bolting Zeus, had a brilliant idea that was not adapted in the pig industry in America until the 1960s, 4000 years later. It was a miraculous solution to both of the problems: the mounds of manure and the smell! Hercules used his mighty arms to divert the flow of the rivers Euphrates and Tigris upstream from the barns, and the combined flow of the two rivers **FLUSHED THE WASTES AWAY**, and simultaneously took the **SMELL AWAY.** This

triumphant feat of Hercules has served Man for millennia and was the idea behind the "water closet" invention [*flushing toilets inside homes; thousands of milliliters of clean water are used to take **away** a few grams of Man's excretions*]. I have named it "***The Hercules Principle***", which states, "***The solution to pollution is ... dilution!***"

> "***The SOLUTION to POLLUTION...is... DILUTION!*** Hercules, 4000 bn

[*There is more to cousin Hercules legend; Hercules compressed and depressed the organic matter of the manure underground into the river deltas in the Persian gulf, where the wastes fermented into **biogas and oil** that are now in full circle, using the biogas and the oil to run our cars and factories, make plastics, and re-pollute our environment, but that is another one of my stories*]!

Diluting pollutants to levels that could be assimilated by the water of the rivers, or the soil, or the air of the atmosphere worked well as long as the materials thrown away were organic in nature, thus Nature could re-use them! So humans settled upstream and upwind along rivers thus having their wastes and smells be taken **AWAY** by the flowing rivers and the blowing winds. However, once Man started synthesizing materials that could not be degraded biologically, and the quantities of wastes discharged became several times greater than the assimilation capacity of the limited volumes of water, air, and topsoil of the earth, then global pollution became a serious problem that could not be solved using ***Hercules Principle***, i.e., **dilution**.

Those of us who watched live astronaut Neil Armstrong walk on the Moon on July 20, 1969 will recall that, aside from the excitement and pride for the exploit, **dust** was the most striking feature of the Moon landscape. The Moon was dead! Then came those incredible photos of the rivers in Cleveland full of silt and sewage penetrating the sanctity of Lake Erie. It was such pictures that made us change our course: Earth Days were instituted worldwide, and environmental protection ministries were added in the government hierarchies in all of the countries of the world. For the last 40 years, not even a millisecond in the long history of Man, Ecology and Economy have finally become synergistic concepts rather than antagonistic opponents.

> ***"Ever since sailor Columbus re-discovered the New World, and the rush to the vast expanses of the Americas began, Man believed that there was "ALWAYS MORE AWAY". In the meantime Man's population grew from millions to billions.***
> ***On July 20, 1969, when Man landed on the Moon and saw that the Moon is dead, and the Earth was dying, it finally dawned on MAN that "There is.... NO MORE AWAY!*** Eliseo

EGG: PRODUCT OR BY-PRODUCT?

The question as to which came first the egg or the chicken is no longer relevant. What is a relevant question is the mystery: manure or egg is the product, [*i.e. the resource*], or the by-product, [*i.e. the waste*]? Both the manure and the egg come out from the same orifice of the chicken, so it is a logical question that should be answered **philosophically**.

Once upon another time 70 years ago, as part of the international aid programs of the USDA, a remote village in the middle of nowhere received thousands of chicks and bags of feed, but without explanations as to what to do with them. After the chicks started laying eggs, the villagers noted that one thing went into the front of the chicken, but two things came out from the back end. They wondered which of these two things was the product and which was the by-product? The villagers asked for clarification, and the USDA dispatched a 3-member panel of experts to look into the matter. One was an expert on manure, an agricultural **ENGINEER.** Since the end products were to be used for human food, the second man chosen for the mission was a poultry **NUTRITIONIST. A**nd, of course, as is customary anymore, a **WOMAN** was added as the third member of the committee.

Criteria for determining what is a product and what is a by-product
The panel members were paid by the day, so they took their time to methodically and objectively develop **criteria** with which to define what was a ***product***, which would mean huge investments, and which was a by-product, which would mean nothing! You see, since the days of the Great Depression in the 1930s when the council of economic advisers was installed within the White House, the gross national ***product*** [GNP] became the criterion by which national progress was to be measured!

The Engineer proposed as the principal criterion **QUANTITY**. He weighed the eggs and the amount of manure excreted. The Engineer announced triumphantly that on the basis of quantity the manure was the product and the egg the by-product.

The Nutritionist chided him for jumping to conclusions on the basis of quantity, a stereotypical engineering approach, the Nutritionist alleged; the Nutritionist said that the criterion must be **QUALITY** not quantity, and that protein content was a quality criterion since the product was to be used for food. So he measured the crude protein content of the manure and that of the egg, and the results indicated that since the crude protein content of the manure was higher than that of the egg, the manure was the product and egg the by-product. [*"Farthermore", the Nutritionist declared that the manure contained more protein and less fat than McDonald's Mac Muffins, and that it even tasted better!*]

The Woman chided both the engineer and the nutritionist as being typical men for using all that scientific jargon to confuse people. "***It is the ODOR, stupid,***" she cried. She picked up the egg, cleaned it, displayed tantalizingly the sexy shape of the pretty, white egg, sniffed it to show that it did not smell, and then turned with disgust at the pile of ugly blackish manure splattered on the ground and turning her nose away from that smelly mess, declared triumphantly that egg was the product and manure was a waste because it smelled!

Thus on the basis of smell, it was decided that the eggs are resources and manures are wastes. Eggs, being a resource, received great attention by the politicians and the scientific community, with departments of egg production instituted at major universities and millions of dollars spent to train egg specialists and poultry farmers. The result was that egg production improved so much that today eggs are cheaper than they were 70 years ago and available everywhere in the world.

On the other hand, since manure was declared a waste because it smelled, manure was neglected and no funds were allocated for research. While thousands of papers were published on eggs, there was a dearth of scientific work on manure management for decades. Before the 1960s, two, yes only 2, bulletins on manure were published: one in 1930 by the Illinois State Water Survey [*on paunch manure digestion*], and another in 1939 by the Ohio Ag. Exp. Station [*on barnyard manure*].

It is true that manure smells, but so do eggs if they are neglected and left out in the sun; the eggs would smell worse than manure [*we all know the pungent smell of a rotten egg*]. So the egg, a resource, becomes a waste when neglected because it starts to smell. Manure, labeled a waste because of its smell, when placed on soil becomes a resource for the plants; the plants do not care whether the fertilizer is smelly or not; what they care about is the source of nitrogen, and manure is the best source good nitrogen. SO MANURE BECOMES A RESOURCE WHEN IT IS PROPERLY MANAGED!

It is a fallacy to differentiate between resources and wastes; all materials are resources, just like we no longer must differentiate between economy and ecology! Manure inside a house smells, but when placed in the field is a resource; so the definition of what is called a waste is really a RESOURCE OUT OF PLACE.

Most people think that wastes are the ones that cause pollution. It is true that if we were to dump manure in a river, the river would get polluted; however, that river would also get polluted if we dumped equivalent amounts of eggs into it, even though eggs are designated as a resource. Throwing milk, another resource from the livestock industry, would cause even worse pollution than equivalent amounts of manure that is defined as a waste. So it is not wastes that cause pollution; it is discharging into the rivers materials in excess of what the rivers can assimilate that cause pollution.

> "***When you throw something away and nobody and nothing picks it up and uses it, that is pollution***". Eliseo

A good example that you may use for your children, so they can become aware of their environmental responsibility, is that they cause pollution when they throw away the wrappings from gum or potato chips bags, because neither rivers nor land nor our air can assimilate those indestructible wrappings.

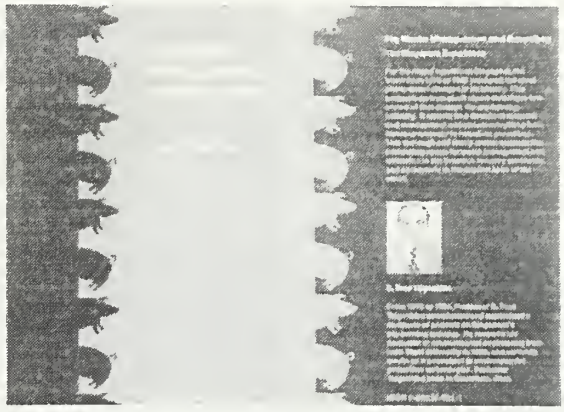
> "***The Solution to Pollution is the 3Rs: Reduce, Recycle, Reuse***"! Eliseo

So the way to solve the pollution problem is to look for ways to reduce the amount of materials that are designated as wastes and are neglected, to force companies to re-use, *in situ*, as much as possible the by-products created by them, and, above all, to re-cycle and re-use whatever we create, just as the ***Creator*** does with us!

REDUCE, RECYCLE, REUSE

The most comprehensive large commercial pig farm waste treatment plant designed with the 3 Rs in mind, built accordingly, operated for a minimum of 3 years, monitored daily and the

concept and the data researched and analyzed by a groups of independently qualified engineers and scientist was in Singapore in the 1980s.



Yes in the tiny country of Singapore, which had a pig population of over 1 million to cater to the daily needs for fresh pork meat of its 2 million Chinese citizens. I, as chief technical adviser assigned by FAO of the UN to the government, was in charge of this unique plant. I went to Singapore on 1-year's leave from Ohio State U. but stayed 12 years. I was involved in the design, the construction, and the evaluation of the plant, and wrote a book[7] about it! The book explains in sufficient detail the work that was carried out and the development of design parameters and criteria for pig housing integrated with wastewater collection and management in properly designed PFA. Thanks to research and development grants from Australia and Canada, extensive pioneer work was carried out in odor travel from pig farms, single cell protein, high-rate algae ponds, fungal fermentation, on recycling systems, on biogas recovery and re-use, and in all aspects of pig manure handling and disposal. [*My book is out of print, unfortunately, but I have donated a copy to the University of Illinois Library*]

I also witnessed the demolition of the plant, which coincided with the end of pig rearing in Singapore. The government changed its policy from self–sufficiency in pork to free trade in 1984, by which time Singapore had become a global metropolis, a hub of high technology manufacturing and services, experienced an unprecedented economic boom, all of which prompted a reversal of the policy of population control to one of giving substantial incentives to educated citizens to bear more children and good-paying positions to entice engineers, scientist, entrepreneurs, artists, et al, from mainland China and from every other part of the world to come and work in thriving Singapore.

Space was needed in the land-limited island for the doubling of the human population. Something had to give, and it turned out to be pigs. Today, the intensive pig farming areas have been turned into expensive, modern, high-rise, high-density residential towns.

Pig Farming Area [PFA] Developments

In 1975, the Singapore government received funding under the United Nations Development Programme [UNDP] for a project on pig wastes. I was invited to head the project. After three years of work, the universality of the problem and the potential of using the results of the Singapore experiment in other tropical countries, where not much research had been carried out at that time, were recognized by UNDP by extending the project funding from 1 to 12 years. Additional external funding was received from the International Development Research Centre of Canada [IDRC], the Australian Development Assistance Bureau [ADAB], Association of South East Asia Nations [ASEAN], and others. The Ponggol Pig Waste treatment plant was built

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[7] Taiganides, E P. 1992. *Pig Waste Management and Recycling.* . International Development and Research Centre, IDRC, Ottawa, Canada. 368 pp.

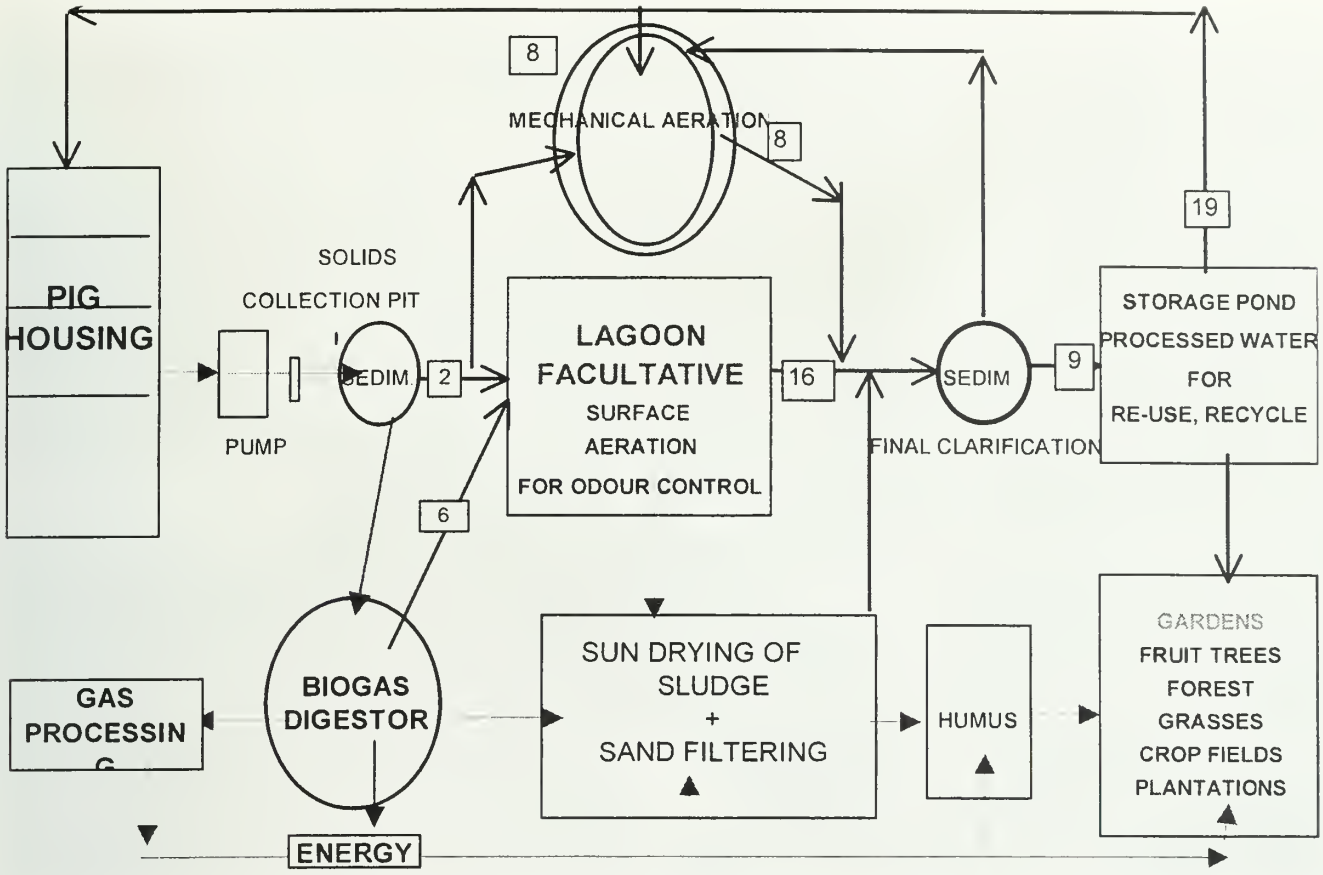
in 1984. Some 40 graduate researchers from Asia and other parts of the world took part in the evaluation of the operation of the plant.

One of the visionary decisions made by the government was to impose, in 1980, an "***environmental levy***" per pig slaughtered, and to use the accumulated millions of dollars to partially fund high quality treatment plants on each farm. To accomplish this, we invited companies from around the world to bid for such treatment plants. Needless to say the response was great.

Of the over 100 companies from Japan, Europe, Australia, and the Americas, which showed interest, 13 were approved, but 4 of them had to built demonstration plants because their proprietary technologies had not been independently verified. Thus it was possible to study in detail the operation of several designs of biogas plants, nitrogen removal plants, besides the Ponggol waste treatment plant. All the companies that built demonstration plants were compensated from funds accumulated by the environmental levy, along with all the farmers, before pig farming ceased in Singapore in 1990.

The details of the design parameters used to design each of the treatment modules, which could be evaluated independently of other modules, the size and capacities, the costs of construction and operation are all given in my books [*References 7 and also in Reference 6*]. Suffice to say that the information derived from this plant is priceless as there are no other publications that I know of that contain all the data of a fully functioning pig waste treatment plant consisting of several unit operations that could be isolated for evaluation and which were operated for three years continuously and their operations were monitored, recorded and published in full detail.

The unit operations and modules of treatment incorporated into the Ponggol Pig waste treatment plant are shown in the drawing below.



The 3Rs: Reduce

To reduce the volume of wastewater generated by flushing, the barns for the 20000 pigs were built on a 1% slope [*See photo below*]. To reduce the amount of fresh water used, which in Singapore was limited unless one paid for expensive city water, a maturation pond was built to store the treated wastewater so that it could be used again for flushing.

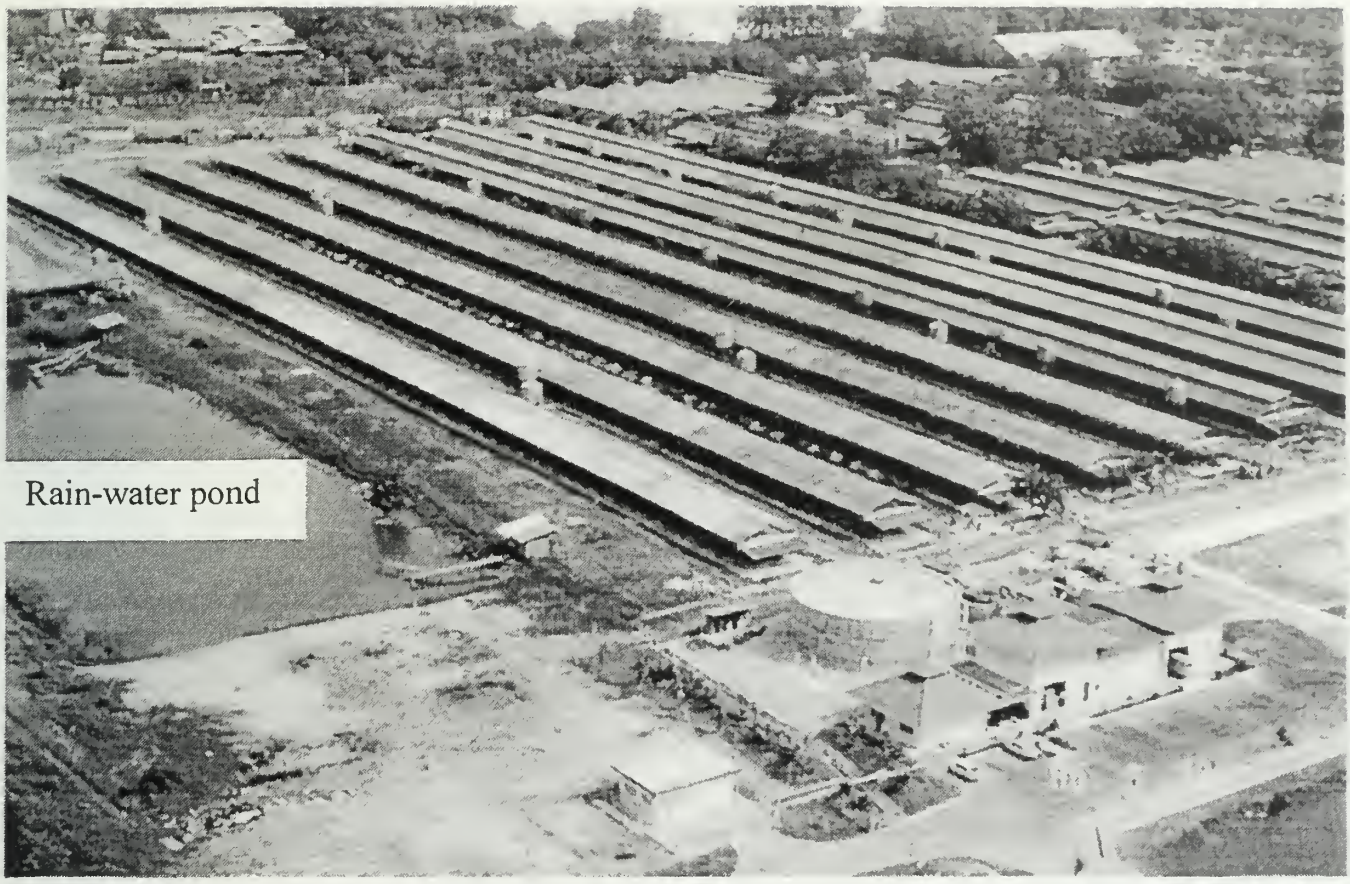
The 3Rs: Recycle

As can be seen in the above drawing, the treated wastewater, after maturation, was recycled for flushing. The nutrients of the manure were extracted, processed, and recycled as tree growth promoters. Because a large segment of the Singapore population is Muslim [*for whom, and for the Jews, pigs are "**haram**", that is, forbidden to be eaten or touched*], the treated solid could not be used as soil additives in vegetable production.

The 3Rs: Re-Use

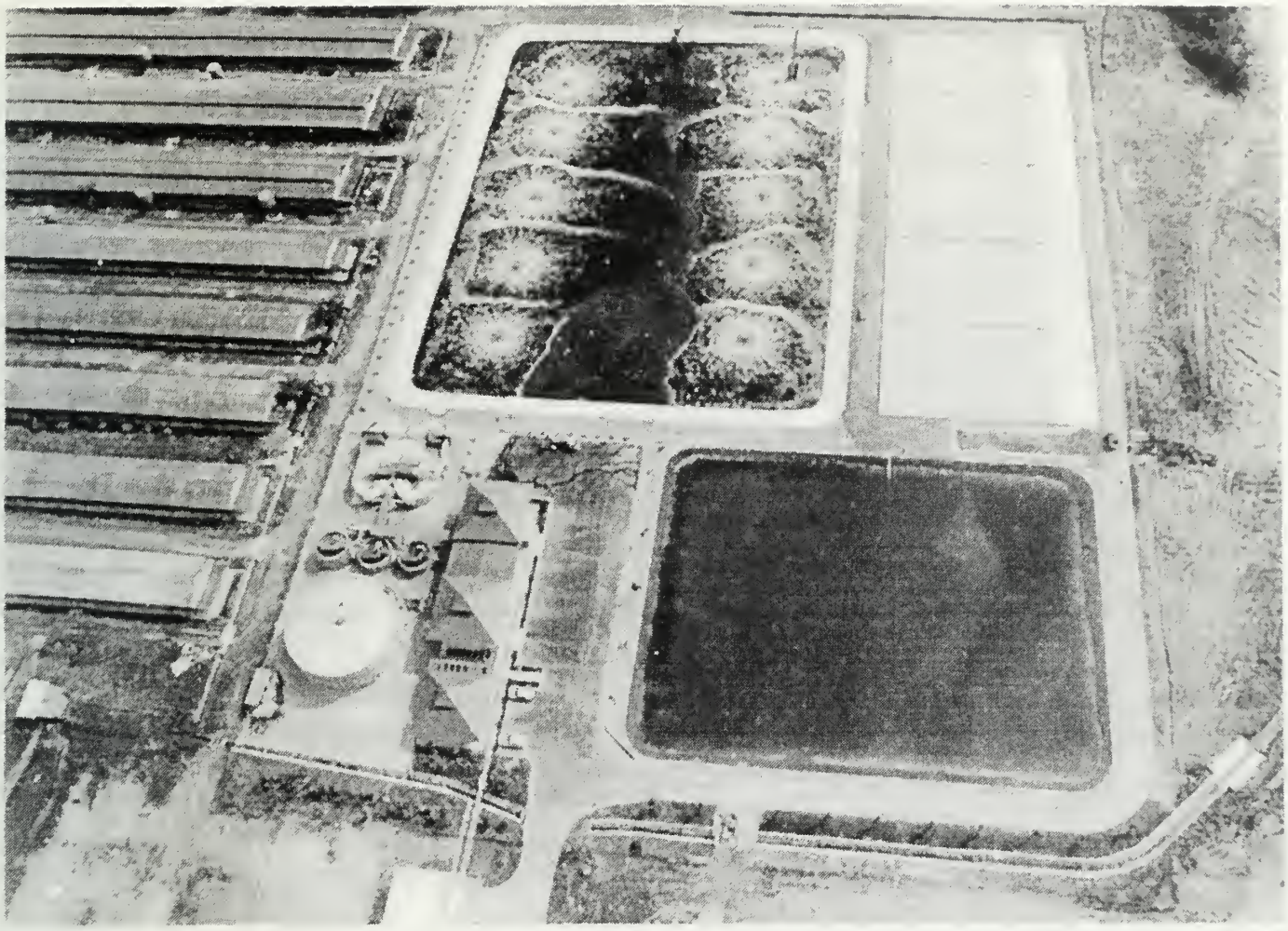
The solids were separated at the beginning of the process and were digested and stabilized, and biogas was recovered and was used to as the energy source to generate electricity to power the surface aerators that were installed to moderate the odors since dense residential housing was less than a mile away. The treated water was re-used on the farm for flushing and cleaning the pens, and the plant nutrients in the stabilized solid were dried, and, after composting, re-used

Two aerial photos of the Ponggol pig waste treatment plant are given in which you could identify the unique design of the barns and all of the major unit treatment modules employed in the Ponggol Pig Wastewater treatment Plant [*Data and details are in my book, footnote 7*].



The first picture shows the long [*1000 feet*], narrow [*to facilitate good ventilation in the tropical climate of Singapore*], open on the sides pig houses built on a 1% slope [*the longest barns in the world at the time*] to accommodate easy flushing and reduce the volume of wastewater. In the forefront are the offices with the laboratories to test and monitor the performance of the treatment modules: the biogas digester, the solids separation sedimentation tanks, final clarifier, and 2 oxidation ditches.

The second picture is a view of the wastewater treatment modules: the sand filter beds, the facultative lagoon with the surface aerators, maturation pond for the clarified effluent before recycling the treated water for flushing, the offices with the laboratories, biogas digester, oxidation ditch, the primary and final clarifiers, and the collection pit and pumping station at the end of the barns of the farm of 35,000 pigs. The composting of the sludges was carried out to the right of the sand filter beds.



END

Legal Issues of Livestock Odor and Waste Management

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Introduction: Environmental Regulation of Agriculture

Statutes, regulations, and common-law principles govern the activities of livestock producers in the United States. The federal government and 50 individual states have authority to enact laws; federal and state administrative agencies enact regulations to implement these laws.[2] In addition, federal and state courts decide cases that affect agricultural producers. Though producers are subject to many of the same laws that govern other individuals and companies, some laws and regulations apply specifically to agriculture, while others provide exemptions for agriculture.

In recent years, the environmental effects of agriculture, especially livestock production, have become the focus of both regulation and litigation. Environmental liability rules that apply to agricultural producers come in part from federal and state environmental laws and regulations. For example, the federal Clean Water Act and Clean Air Act, among other laws, include provisions that apply to livestock producers. But some agricultural activities have been excluded from environmental regulation or have enjoyed safe harbors in laws that apply to other industries.[3] Moreover, federal subsidies are often available to farmers who implement practices that reduce pollution, and the 2002 Farm Bill continues some environmental subsidies.[4]

This paper first provides background on environmental statutes and regulations, as well as common-law tort liability. It then focuses on federal law provisions, especially under the Clean Water Act and the Clean Air Act, that affect livestock producers.[5]

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[1] This paper is based on work supported by C-FAR Project No. 99Si-085-3A (Legal Issues in Swine Odor and Waste Management) and by CREES, USDA, Project No. ILLU-05-309.

[2] Local governments – counties, townships, and municipalities -- have authority to regulate (e.g., zoning), but agricultural operations often enjoy some exemptions from local regulation.

[3] On these issues, see, e.g., J.B. Ruhl, *Farms, Their Environmental Harms, and Environmental Law*, 27 Ecology Law Quarterly 263 (2000).

[4] Farm Security and Rural Investment Act, Pub. L. No. 107-171, 107th Cong., 2d Sess., 116 Stat. 134-540 (2002).

[5] For more detail on these federal laws, see Grossman, Margaret Rosso (one of 16 authors, chaired by P.R. Hagenstein), Air Emissions from Animal Feeding Operations: Current Knowledge, Future Needs, chap. 6 (National Research Council, National Academy of Sciences, March 2003).

Statutes and Regulations

Federal environmental laws apply in all 50 states to establish minimum environmental criteria for the nation. Many federal environmental laws include provisions that allow individual states to implement federal laws within their territories. With federal approval and oversight, states enact laws and regulations that meet federal regulatory criteria, issue environmental permits, and enforce the laws. In most cases, states can enact provisions that are stricter than federally required. States may also enact independent environmental laws, as long as those laws do not interfere with federal requirements. Those who violate environmental laws face enforcement from federal and state governments.

Federal and state statutes impose legal obligations and authorize administrative, civil, or even criminal liability for failure to comply. Violation of a statutory or regulatory provision or a requirement imposed in a state or federal environmental permit can result in an enforcement action. The US Environmental Protection Agency (EPA) implements and enforces most federal environmental laws; state environmental agencies have enforcement authority under federally-approved state programs. When authorized by statute, penalties can be assessed in administrative proceedings (e.g., by the EPA) or in a civil judicial enforcement action (i.e., in court). Environmental statutes prescribe maximum monetary penalties, but penalties are sometimes measured by the level of environmental harm (e.g., value of fish killed by a manure spill). Most federal statutes also impose criminal liability (fines or imprisonment) for individuals or business entities, and the number of criminal prosecutions for serious offences has increased in recent years.

Common-law Tort Principles

Livestock producers, like other individuals and entities in the US, face liability under common-law tort principles, usually based in state law, when their actions cause environmental or other damage to the person or property of others. Of course, producers themselves can (and sometimes do) raise claims in tort when they suffer harm from actions of others. Tort claims associated with livestock facilities often result from the presence of odors, but manure spills and improper manure application have also led to lawsuits against producers. Remedies available in tort cases include monetary damage awards and, less often, injunctions of defendant's behavior.[6]

Nuisance is the common-law remedy that applies when a producer's activities interfere unreasonably with another person's use and enjoyment of land, injure life or health, or interfere with public rights. A private nuisance arises from an "invasion of another's interest in the private use and enjoyment of land."[7] Private nuisance often results from an activity on defendant's land that interferes unreasonably with use of plaintiff's neighboring land. A public

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[6] This description of tort claims follows Margaret Rosso Grossman, *Genetically Modified Crops in the United States: Federal Regulation and State Tort Liability*, 5 Environmental Law Review 86-108 (2003).

[7] Restatement (Second) of Torts § 821D (1979).

nuisance is "an unreasonable interference with a right common to the general public."[8] A public nuisance usually affects a significant number of people; cases are normally brought by a government official or (less often) by an individual with a "special injury" (an injury different in kind from members of the general public). A few recent cases have used the theory of anticipated nuisance to prevent construction of livestock facilities, which would (arguably) cause a nuisance.[9]

Because all persons have the right to reasonable use and enjoyment of their property, nuisance involves a balance of competing interests. A defendant, for example, cannot cause unreasonable harm to a plaintiff, but the plaintiff must endure some inconvenience to accommodate the defendant's legitimate land-use activities. States have enacted right-to-farm laws that protect certain agricultural operations from nuisance suits;[10] most apply when the farm was in operation for a year (or more), and changes in land use near the producer led to the nuisance claim. But producers who violate environmental laws or whose practices are considered improper or negligent may remain vulnerable to nuisance suits.[11]

Activities that lead to a nuisance claim may also result in a claim of trespass. Trespass is a physical invasion of land that interferes with the plaintiff's exclusive right to possession and causes damage to the property. It occurs when the defendant enters plaintiff's land or when defendant knowingly causes something (e.g., pollution) to enter plaintiff's land.

The tort of negligence focuses on defendant's conduct. Plaintiff must usually prove that defendant had a duty to conform to a specific standard of conduct (to act with reasonable care), the defendant breached that duty, the plaintiff suffered harm, and the defendant's breach of duty caused plaintiff's injury. Thus, tort cases based on negligence require the plaintiff to prove that defendant's conduct was unreasonable, e.g., by proving failure to comply with accepted (or legally required) waste handling practices.

Strict liability applies when the defendant causes injury while carrying out an activity characterized as abnormally dangerous or ultra-hazardous. In strict liability, the defendant will be liable for damages, even if the activity was carried out with all reasonable care.[12] That is, the plaintiff need not prove that defendant's conduct was negligent. Activities associated with livestock production are not likely to be considered ultra-hazardous.

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[8] *Id.* § 821B.

[9] See, e.g., Nickels v. Burnett, 2003 Ill. App. Lexis 1278, No. 02-MR-175 (2d. Dist. App., 20 Oct. 2003) (affirming a preliminary injunction against a hog confinement facility).

[10] See, e.g., Margaret Rosso Grossman & Thomas G. Fischer, *Protecting the Right to Farm: Statutory Limits on Nuisance Actions Against the Farmer*, 1983 Wisconsin Law Review 95, 119 (1983). .

[11] The Iowa Supreme Court held that an Iowa right to farm law was unconstitutional. Bormann v. Board of Supervisors, 584 N.W.2d 309 (Iowa 1998), *cert. denied*, 525 U.S. 1172 (1999).

[12] Restatement (Second) of Torts § 520 & comment f (1979). To identify an abnormally dangerous activity, courts consider factors like the degree of risk, likelihood of harm, ability to eliminate risk, commonness of use, value to society, and appropriateness of the location.

Livestock Producers and the Clean Water Act

The federal Clean Water Act (CWA),[13] was designed to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters."[14] The CWA protects water quality through regulatory measures, including ambient water quality standards, limits on effluents, and permits. Under the CWA, concentrated animal feeding operations (CAFOs) are defined as "point sources"[15] of water pollution. Therefore, they are subject to requirements of the National Pollutant Discharge Elimination System (NPDES) and may discharge pollutants only in compliance with an NPDES permit.[16] Animal feeding operations (AFOs) that are not regulated as point sources are considered nonpoint sources, subject to rather weak state planning programs under the CWA.[17] Some nonpoint sources will also be regulated through state total maximum daily load (TMDL) programs required by the CWA.[18]

The EPA first enacted regulations for CAFOs in the 1970s: Effluent Limitations Guidelines and Standards (ELGs) in 1974,[19] and NPDES permit requirements in 1976.[20] Under these regulations, only a small number of AFOs were required to obtain NPDES permits. In 2001, the EPA estimated that about 12,660 US livestock facilities confined more than 1000 animal units, but that only about 4000 facilities had NPDES permits.[21]

Consolidation of the livestock industry, with fewer and larger facilities, led to a review of the CAFO regulations, beginning in 1992.[22] In 1998, the US *Clean Water Action Plan* identified polluted runoff from agriculture as one of the serious water quality problems facing the United

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[13] 33 USC §§ 1251-1387.

[14] *Id.* § 1251(a)

[15] "The term 'point source' means any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, ... concentrated animal feeding operation, . . . from which pollutants are or may be discharged. This term does not include agricultural stormwater discharges and return flows from irrigated agriculture." 33 USC § 1362(14).

[16] *Id.* § 1342.

[17] *Id.* §§ 1288, 1313.

[18] *Id.* § 1313(d). A TMDL establishes the amount of a pollutant that an impaired water body can receive without exceeding water quality standards. Both point and nonpoint sources of the pollutant may be considered in establishing TMDLs, which are to be used where effluent limitations are not stringent enough to achieve water quality standards. See Pronsolino v. Nastri, 291 F.3d 1123 (9th Cir. 2002), *cert. denied*, 123 S. Ct. 2573 (2003).

[19] 39 Fed. Reg. 5704 (1974), codified at 40 CFR part 412.

[20] 41 Fed. Reg. 11458 (1976), codified at 40 CFR part 122.

[21] 66 Fed. Reg. 2960, 2968-69; EPA, Proposed Revisions to CAFO Regulations. Frequently Asked Questions, http://www.epa.gov/npdes/pubs/cafo_faq.pdf (last visited 29 Sept. 2003).

[22] See 66 Fed. Reg. 2960, 2965-66 (2001). In the late 1990s, pork producers and the poultry industry worked with the EPA to develop voluntary environmental compliance programs. 66 Fed. Reg. at 2966.

States and recommended that EPA and USDA develop a national strategy to minimize environmental and public health impacts of livestock production.[23] After publishing preliminary documents,[24] USDA and EPA cooperated to prepare the *Unified National Strategy for Animal Feeding Operations*.[25] This *Strategy*, from March 1999, established a national goal to minimize water pollution from confinement facilities and land application of manure. It indicated that AFOs would be expected to develop and apply comprehensive nutrient management plans.

New Federal CAFO Regulations

In January 2001, EPA proposed regulations that would revise both the NPDES provisions that define CAFOs and require permits and the ELGs that set technology-based standards for effluent limitations from CAFOs.[26] After considering comments and amending the proposal, the EPA enacted its new regulations in December 2002.[27] The EPA's intent was to enact regulations "based on sound science and economics, promote emerging technologies, and protect watersheds."[28] The agency's guiding principles were simplicity and clarity, emphasis on large CAFOs, flexibility for states, and sound nutrient management planning. The new regulations are expected to increase the number of facilities that will be defined as CAFOs and must therefore operate under NPDES permits. In Illinois, for example, the new regulations could affect 500 Large CAFOs and 2700 Medium CAFOs.[29] The following discussion briefly describes producers' obligations under the regulations.

NPDES Permits

Under the NPDES regulations, an "animal feeding operation" (AFO) is a lot or facility where animals are confined and fed or maintained for a total of 45 days or more in any 12-month period, and where crops, vegetation, forage growth, or post-harvest residues are not present during the normal growing season. A "concentrated animal feeding operation" (CAFO) is an

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[23] EPA & USDA, Clean Water Action Plan, http://www.cleanwater.gov/action/ (1998) (last visited 25 Mar. 2003).

[24] EPA, Strategy for Addressing Environmental and Public Health Impacts from Animal Feeding Operations (Draft, Mar. 1998), http://www.epa.gov/npdes/pubs/astrat.pdf (last visited 29 Sept. 2003); EPA, Compliance Assurance Implementation Plan for Animal Feeding Operations (Mar. 1998), http://www.epa.gov/compliance/resources/policies/civil/cwa/cafostrat.pdf (last visited 9 Sept. 2003).

[25] USDA & EPA, Unified National Strategy for Animal Feeding Operations (final, March 1999), http://cfpub1.epa.gov/npdes/afo/ustrategy.cfm?program_id=7 (last visited 25 Mar. 2003).

[26] 66 Fed. Reg. 2960 (2001).

[27] The regulations appeared in the Federal Register in February 2003, 68 Fed. Reg. 7176 (2003), effective 14 April 2003, though some requirements apply later. EPA received more than 11,000 comments on its proposal and proposed amendments. 68 Fed. Reg. at 7187-88.

[28] 68 Fed. Reg. at 7182.

[29] Both environmental NGOs and farm organizations have filed lawsuits to challenge the regulations. Cases brought by environmentalists and industry will be heard in the US Court of Appeals for the Second Circuit.

AFO defined by regulation as a Large or a Medium CAFO or specifically designated as a CAFO.[30]

Animal numbers define Large and Medium CAFOs.[31] A Large CAFO is an AFO that stables or confines, for example, 2,500 swine weighing 55 pounds or more, or 10,000 swine weighing less than 55 pounds.[32] A Medium CAFO has fewer animals: 750 to 2499 swine weighing 55 pounds or more, or 3000-9999 swine weighing less than 55 pounds. A Medium CAFO also discharges pollutants into waters of the US either directly or through a man-made device.[33] Any other AFO that discharges water pollutants can be designated as a CAFO if it contributes significantly to pollution of US waters.[34] Under prior regulations, no AFO was considered a CAFO if it discharged only in a 25-year, 24-hour storm event, but that exception has been omitted from new regulations that define CAFOs.[35]

All CAFOs must operate under an individual or general NPDES permit.[36] Facilities newly defined as CAFOs under the regulation must seek to obtain coverage under a permit no later than 13 February 2006; facilities already defined as CAFOs under prior regulations were required to have or apply for a permit by 14 April 2003.[37] Both production areas and land application areas are now regulated.[38] Discharges of manure, litter, or process wastewaters as a result of applications to land under control of the CAFO are subject to NPDES permit requirements. As required by the CWA, however, agricultural storm water discharges are excepted.[39]

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[30] 40 CFR § 122.23(b)(1), (2). Two or more AFOs under common ownership are considered a single AFO for determining the number of animals at an operation if they are adjoining or use a common waste disposal area or system.

[31] 68 Fed. Reg. at 7189. Prior regulations used animal units, rather than animal numbers. The new regulations also apply to more types of facilities -- e.g., poultry facilities using "dry" manure handling and veal calf operations are now regulated.

[32] 40 CFR § 122.23(b)(4). Other Large CAFOs hold 700 mature dairy cows, 1,000 veal calves, 1,000 cattle other than mature dairy cows or veal calves, 500 horses, 10,000 sheep or lambs, 55,000 turkeys, 125,000 chickens (other than liquid manure handling), 30,000 laying hens or broilers (using liquid manure handling), 82,000 laying hens (other than liquid manure handling), 30,000 ducks (other than liquid manure handling), or 5,000 ducks (liquid manure handling).

[33] *Id.* § 122.23(b)(6).

[34] *Id.* § 122.23(c).

[35] *Id.* part 122, Appendix B (2001). The 25-year, 24-hour storm event remains relevant in the context of ELGs.

[36] *Id.* §§ 122.21(a)(1), 122.23(d). When a general permit has been approved, individual facility operators file a notice of intent for coverage under the general permit and must include the information required for individual permits. *Id.* §§ 122.21(i), 122.28(b)(ii).

Compliance with permit requirements normally constitutes compliance with requirements of the CWA. 33 USC § 1342(a), (k).

[37] 40 CFR § 122.23(g). Other deadlines apply to new or modified operations that will be CAFOs.

[38] 40 CFR § 122.23(e). These areas are defined in § 122.23(b)(3), (8) and § 412.2(e), (h).

[39] 33 USC § 1362(14). Regulations thus prescribe that "where the manure, litter or process wastewater has been applied in accordance with site specific nutrient management practices that ensure

For Large CAFOs, permits will impose technology-based standards established by the newly-enacted ELGs, discussed below. Because ELGs do not apply to other CAFOs, the permit writer will use professional judgment to establish technology-based requirements for production and land application areas of the CAFO.[40] All permits must require CAFOs to develop and implement (by 31 December 2006) a nutrient management plan that includes best management practices and procedures.[41] Permits must impose recordkeeping requirements, annual reports, and (for Large CAFOs only) information and recordkeeping about manure transfer. CAFO operators must maintain permits, even after closure, until there is no remaining potential for discharge.[42]

The CWA allows states to implement the NPDES permit program, provided that state requirements are at least as strict and as broad as federal requirements.[43] At the end of 2002, 45 states (including Illinois) and the Virgin Islands had authority to implement the NPDES program;[44] in the other states and territories, the US EPA regional offices issue NPDES permits. To comply with new regulations, states must revise their NPDES programs within one year (by February 2004) or, if legislation is necessary, two years. Procedures for issuing a general permit may take an additional year.[45]

Effluent Limitations Guidelines

The new EPA regulations establish ELGs and other performance standards for Large CAFOs that confine horses and sheep; ducks; dairy cows and cattle other than veal calves; and swine, poultry, and veal calves.[46] A separate subpart of the regulation governs each animal group, though many requirements are similar or identical. Regulations apply to manure, litter, and process wastewater discharges from Large CAFOs.

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appropriate agricultural utilization of nutrients. . . , a precipitation-related discharge . . . is an agricultural stormwater discharge." 40 CFR § 122.23(3).

[40] 68 Fed. Reg. at 7226.

[41] 40 CFR § 122.42(e).

[42] *Id.* § 122.23(h). A Large CAFO may be exempt from coverage under an NPDES permit if it meets rather stringent criteria for a determination of "no potential to discharge . . . under any circumstance or climatic condition." *Id.* § 122.23(d)(2), (f). A Medium CAFO does not qualify for this exemption, likely because a Medium CAFO, by definition, discharges pollutants.

[43] 33 USC § 1342(b).

[44] 68 Fed. Reg. 7176, 7185 (2003). Oklahoma administers its NPDES program, but has no authority to regulate CAFOs. States without NPDES permitting authority are Alaska, Arizona, the District of Columbia, Idaho, Massachusetts, New Hampshire, and New Mexico. No tribes are authorized, nor are Puerto Rico and other territories. *Id.* A brief summary of state NPDES implementation and other regulation of CAFOs appears at 66 Fed. Reg. at 2968-70.

[45] 68 Fed. Reg. at 7204. EPA expects most authorized states to meet the deadline for revised regulations. EPA, CAFO Implementation Progress Report Through 7/30/03 (2003).

[46] 40 CFR part 412. Subparts A (horses and sheep) and B (ducks) are less detailed than Subparts C (dairy cows and cattle other than veal calves) and D (swine, poultry, and veal calves).

The ELGs prescribe standards for CAFOs with the animal types listed above and under specific technology standards.[47] For most animals and technology standards, including swine, there shall be no discharge of process wastewater pollutants (or of manure, litter, or process wastewater pollutants) into US waters from the production area of the facility. When precipitation causes an overflow, discharge into US waters is permitted only if the production area is "designed, constructed, operated and maintained" to accommodate runoff and direct precipitation from a 25-year, 24-hour rainfall event[48] and other requirements are met.[49] These include visual inspections, depth markers on open liquid impoundments, prompt corrective actions, proper handling of dead animals, and detailed recordkeeping for production areas.[50]

Standards for CAFO land application areas require the operator to develop and implement best management practices (BMPs) and to maintain detailed records.[51] BMPs for land application govern CAFOs that confine swine, as well as dairy and beef cattle, poultry, and veal calves. Each CAFO must develop and implement a nutrient management plan "based on a field-specific assessment of the potential for nitrogen and phosphorus transport from the field and that addresses the form, source, amount, timing, and method of application of nutrients on each field."[52] Application rates must minimize nitrogen and phosphorus transport; manure and soil must be analyzed; and equipment must be inspected. The plan should be based on the most limiting nutrient. That is, when soils have high phosphorus, the plan must be phosphorus based; with low phosphorus, plans can be nitrogen based. More land to apply manure is usually required for a phosphorus limit.[53] The nutrient management plan must normally require a 100-foot setback, or a 35-foot vegetated setback, from (conduits to) surface waters.[54]

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[47] These include BPT (best practicable control technology currently available), BCT (best conventional pollutant control technology), BAT (best available technology economically achievable), and NSPS (new source performance standards).

[48] Regulations define the 25-year, 24-hour rainfall event as "precipitation events with a probable recurrence interval of once in . . . twenty-five years." 40 CFR § 412.2(i). In Midwestern states (Illinois, Indiana, Iowa, Kentucky, Michigan, Minnesota, Missouri, Ohio, Wisconsin), the 25-year, 24-hour rainfall amounts ranged from 3.5 to 7 inches. Floyd F. Huff & James R. Angel, Rainfall Frequency Atlas of the Midwest (Champaign, IL: Illinois Water Survey, Bulletin 71) (1992).

New source performance standards for swine, poultry, and veal calves require facilities to accommodate a 100-year, 24-hour rainfall event. 40 CFR § 412.46. BPT for horses and sheep must accommodate only a 10-year, 24-hour rainfall event. *Id.* § 412.12.

[49] E.g., 40 CFR § 412.31(a) (BPT for dairy cows and cattle other than veal calves, with similar requirements for BCT, BAT, and NSPS). Voluntary site-specific alternative performance standards may be permitted with supporting technical analysis.

[50] *Id.* § 412.37(a), (b).

[51] E.g., *Id.* §§ 412.31(b), 412.4 (BMPs), 412.37(c) (land application records). BMPs apply to Subparts C (dairy cows and cattle other than veal calves) and D (swine, poultry, and veal calves), but not to Subparts A (horses and sheep) or B (ducks).

[52] *Id.* § 412.4(c)(1).

[53] Marc Ribaudo et al., Manure Management for Water Quality: Costs to Animal Feeding Operations of Applying Manure Nutrients to Land at 11, 38. ERS, USDA, Agricultural Economic Report

Complying with the new regulations, especially the nutrient management plan, is likely to increase costs for livestock producers. USDA research on hog farms shows that fewer than half of farms meet the nitrogen-based standard for manure application, and even fewer meet the phosphorus-based standard. Producers in the Cornbelt, where more land is available, can meet the standards more easily.[55] A USDA report published in June 2003 analyzes the costs and benefits of applying manure nutrients to land in compliance with the new EPA regulations.[56]

Air Emissions from Livestock Facilities

Clean Air Act

Air emissions produced by livestock facilities include several pollutants[57] regulated under the federal Clean Air Act (CAA),[58] which governs air quality in the US.[59] Important "substances of concern" emitted by livestock facilities are ammonia, hydrogen sulfide, particulate matter, nitrous oxide, nitric oxide, methane, volatile organic compounds, and odor.[60] Accurate measurement of air emissions from AFOs, however, has proved difficult. The complexity of substances and their sources and varied production and geographic conditions mean that more research on measurement of air emissions is needed.[61]

The CAA includes standards for ambient air quality to protect public health and welfare, special measures for regions that have not attained those standards (nonattainment areas), operating permits for stationary sources of air pollution, control technology for new sources of air pollution, measures to control hazardous air pollutants, and other programs.

No. 824 (June 2003). This report refers to the most limiting nutrient standard, but the regulation is less clear.

[54] 40 CFR § 412.4(c)(2)-(4).

[55] Ribaudo et al., *supra* note 53, at 14, 16.

[56] *Id.* The report is on the Economic Research Service website, http://www.ers.usda.gov.

[57] The CAA defines "air pollutant" as "any air pollution agent or combination of such agents, including any physical, chemical, biological, radioactive . . . substance or matter which is emitted into or otherwise enters the ambient air. Such term includes any precursors to the formation of any air pollutant . . . [identified by the EPA Administrator]." 42 USC § 7602(g).

[58] 42 USC §§ 7401-7671q, as amended.

[59] See Air Emissions, *supra* note 5, chap. 6.

[60] *Id.* at 16, 50-56.

[61] *Id.* at 22.

The EPA implements the CAA and enacts regulations for its various programs.[62] The EPA approves state plans enacted to meet federal requirements,[63] delegates to states the authority to issue operating permits for air pollution sources,[64] and oversees state air pollution control agencies. States normally enact legislation that complies with the CAA and is at least as stringent as federal requirements.[65] States assign responsibility for air quality to state or local air pollution control agencies,[66] which enforce the Act in their territories. States also ensure that their air quality meets federal standards through state implementation plans, permits for air pollution sources, and other measures.

The so-called "criteria pollutants" and the hazardous air pollutants (HAPs) are a major focus of regulation. To regulate criteria pollutants, the national ambient air quality standards (NAAQS) program is central.[67] The CAA prescribes that primary NAAQS should establish levels of air quality that will protect the public health with an adequate margin of safety. Secondary ambient air quality standards, when enacted, should protect the public welfare.[68] The EPA has established primary NAAQS for six criteria pollutants: sulfur dioxide, nitrogen dioxide,

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[62] 42 USC § 7601; see 40 CFR parts 50, 51, 53, 55, 60, 61, 63, 70, 71. E.g., EPA has established national ambient air quality standards (NAAQS) for criteria pollutants, identified maximum achievable control technology for hazardous air pollutants from major pollution sources, and set new source performance standards for facilities that contribute significantly to air pollution. The EPA is also responsible for designating areas where air quality standards have not been met (nonattainment areas). 42 USC §§ 7407, 7501-7502.

[63] If EPA does not approve a state plan, it must implement its own federal plan. 42 USC §§ 7407, 7410.

[64] This is required by the "Title V operating permit program" of the 1990 Clean Air Act Amendments, codified at 42 USC §§ 7661-7661f; 40 CFR parts 70, 71.

[65] 40 CFR § 51.101. In addition to implementing federal CAA programs, some states have enacted air pollution provisions not required by federal law. Some state programs affect livestock facilities. For example, both Minnesota and Texas have state ambient air quality standards for hydrogen sulfide. Minn. Rules § 7009.0080; 30 TAC § 112.31-.34. Livestock production facilities are exempt from the Minnesota hydrogen sulfide standard while, and shortly after, manure is removed from barns or storage facilities. Minn. Stat. § 116.0713.

In 1999, Colorado enacted a special regulation for housed commercial swine feeding operations. This regulation establishes odor standards and requires approved covers for "anaerobic process wastewater vessels and impoundments" to minimize emission of odorous gases. Colorado Air Quality Control Commission, Regulation No. 2: Odor Emission (1999), http://www.cdphe.state.co.us/op/regs/airregs/100104aqccodoremission.pdf (last visited 15 Oct. 2003).

Other states have taken different measures, including setback requirements for large livestock operations. E.g., Illinois Livestock Management Facilities Act, 510 ILCS 77/1-999. These state programs, however, supplement the state SIP and other measures under the CAA.

[66] See 42 USC § 7602(b), defining air pollution control agency.

[67] F. William Brownell, *The Clean Air Act*, *in* Environmental Law Handbook 213, 214 (Thomas E.P. Sullivan ed. emeritus, 17th ed. 2003).

[68] 42 USC § 7409(b)(1), (2).

particulate matter (PM_{10} and $PM_{2.5}$), carbon monoxide, ozone, and lead.[69] In the states, these NAAQS are met by state implementation plans (SIPs) and new source performance standards.

Hazardous air pollutants (HAPs) present a serious threat to human health or the environment. They are identified in a statutory list that can be modified by EPA regulation. [70] The EPA currently regulates 188 HAPs. Precursors of ozone (reactive VOCs) and secondary $PM_{2.5}$ (ammonia), both emitted by livestock facilities, are regulated air pollutants even though they are not listed as criteria pollutants or HAPs.

State Implementation Plans (SIPs) translate national ambient standards into emission limitations that govern individual sources of air pollution. [71] The state SIP must implement, maintain, and enforce the primary NAAQS in the state or an air quality control region in the state.[72] The CAA prescribes the required elements of each SIP,[73] and regulations provide more detailed requirements for state plans.[74] After approval by the EPA, a SIP can be enforced as both state and federal law.

Under the CAA and the relevant state SIP, the livestock producer who plans to construct a new livestock facility may have to obtain an air pollution permit prior to construction or operation, if the facility is large enough to be considered a "major" source, as defined by statute and regulation. Generally, a major source is a stationary source that emits, or has potential to emit, 100 tons per year or more of any air pollutant.

Individual facilities are governed by pre-construction and operating permits issued under state permitting programs. The pre-construction permit requirement applies to a major new source or a major modification of an existing source.[75] Permit requirements in specific states may be more stringent and also govern "minor" new or modified sources.[76] The pre-construction permit will normally include a description of proposed air pollution abatement systems, a determination of

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[69] *Id.* § 7409; 40 CFR part 50. NAAQS protect human health by setting maximum ambient concentrations and averaging time periods for these criteria pollutants.

[70] 42 USC § 7412(b).

[71] Under the CAA, each state has "primary responsibility for assuring air quality within the entire geographic area comprising such State by submitting an implementation plan for such State which will specify the manner in which national primary and secondary ambient air quality standards will be achieved and maintained." 42 USC § 7407(a).

[72] *Id.* § 7410(a)(1).

[73] *Id.* § 7410. This section sets out numerous specific requirements for SIPs.

[74] 40 CFR part 51.

[75] The pre-construction permit is required both under provisions that govern the prevention of significant deterioration (PSD) in areas where NAAQS have been met, 42 USC § 7475, and under provisions for nonattainment areas where NAAQS have not been met, *id.* § 7503. The definition of "major" differs between PSD and nonattainment areas. 40 CFR § 52.51(b)(1); Brownell, *supra* note 67, at 228-32. The permit threshold is lower in a nonattainment area, and permit conditions are stringent.

[76] Brownell, *supra* note 67, at 238.

the allowable emission rate, and other requirements. In addition, most major stationary sources of air pollution are required to obtain operating permits.[77] Permits must include enforceable emission limitations and standards, a schedule of compliance, reporting requirements, and other conditions.[78]

Major sources, as defined by the CAA and EPA regulations, pay an annual permit fee, based on total emissions of regulated pollutants. Fugitive emissions are not considered in determining whether a facility is a "major stationary source" of air pollution.[79] But once the major source threshold (e.g., 100 tons per year of any pollutant) is met, the permit fee is determined by "actual emissions" of all regulated pollutants,[80] including fugitive as well as other emissions.

Most agricultural operations are believed to be minor sources of air pollution; therefore, few agricultural facilities have been required to comply with the operating permit requirement. Environmentalists, however, have argued that many large livestock facilities emit more 100 tons of a regulated pollutant (especially ammonia) per year and should therefore be regulated as major sources.[81] As noted above, however, lack of reliable measurement techniques for some sources has impeded regulatory enforcement.

In practice, enforcement against agricultural operations is often triggered by complaints, especially when operations are perceived to cause a nuisance. If investigation confirms that a violation has occurred, penalties may be assessed against the facility. Violation of CAA provisions, including permit requirements, can result in substantial penalties.[82] For example, the EPA administrator is authorized to file a civil action for an injunction or a civil penalty of up to $25,000 per day for each violation of certain CAA provisions.[83] States, too, have authority to enforce CAA provisions under EPA-approved state programs.

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[77] 42 USC §§ 7661-7661f. The EPA has authority to approve each state's permit plan and each state-issued permit.

[78] States may provide that compliance with the permit is considered compliance with "applicable provisions" of the CAA. 42 USC § 7661c(f).

[79] *Id.* § 7602(j); 40 CFR §70.2. Fugitive emissions have proven controversial, in light of an EPA proposal to call many agricultural air emissions, including emissions from waste lagoons and barns, "fugitive," and thus negate major source requirements for many facilities. Air pollution administrators and environmentalists oppose this proposal. See Lloyd L. Eagan (State and Territorial Air Pollution Program Administers) & Ellen Garvey (Assoc. of Local Air Pollution Control Officials), Letter to Christine Todd Whitman, then-EPA Administrator, 7 Apr. 2003, http://www.sierraclub.org/pressroom/cafo_papers/STAPPA_letter_to_Whitman.pdf (last visited 11 Oct. 2003).

[80] 40 CFR § 70.9.

[81] See. e.g., Environmental Integrity Project et al., Letter to J.P. Suarez, EPA, 2 Sept. 2003, Re: Clean Air Act Investigations and Enforcement at Concentrated Animal Feeding Operations, http://www.rffund.org/eip/docs/CAFOCAAltr9-2-03.pdf.

[82] 42 USC § 7413.

[83] *Id.* § 7413(b). Administrative penalties and criminal penalties are also authorized.

CERCLA and EPCRA

Both the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA)[84] and the Emergency Planning and Community Right-to-Know Act (EPCRA)[85] include reporting requirements that may apply to emissions from large livestock facilities. These federal laws require reports from facilities that release[86] a reportable quantity of certain hazardous pollutants. Hydrogen sulfide, ammonia, and some volatile organic compounds are among the reportable substances released by livestock facilities. For both ammonia and hydrogen sulfide, the reportable quantity is 100 lbs/day (18.3 tons/year).[87]

The EPA has rarely enforced the reporting requirement for livestock facilities that release hazardous air pollutants. But statutory provisions allow citizens to file suit to enforce these laws.[88] Therefore, large livestock operations are vulnerable to citizen suits for failure to report.

Proposed Industry-EPA "Safe Harbor"

Though strict air pollution statutes and regulations have helped to improve US air quality, livestock facilities have posed special issues. Enforcement of applicable provisions of the CAA, CERCLA, and EPCRA requires accurate measurement of emissions, arguably more accurate than present techniques allow.[89] But monitoring air emissions from confinement buildings, feedlots, waste lagoons, and other components of livestock facilities has been controversial. To protect AFOs while scientists develop effective monitoring techniques, representatives of the livestock industry have suggested that EPA implement a livestock and poultry monitoring and safe harbor agreement.[90]

An October 2003 draft of the proposed safe harbor agreement[91] indicates that the safe harbor is intended to address emissions of air pollutants and hazardous substances and to ensure that participating AFOs (eventually) comply with provisions of the CAA and CERCLA, by applying emission-estimating methodologies developed in a monitoring program funded by participating

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[84] 42 USC §§ 9601-9675. CERCLA is sometimes called the Superfund law.

[85] 42 USC §§ 11001-11050.

[86] The CERCLA definition of release (§ 9601(22)(D)) excludes "the normal application of fertilizer."

[87] 40 CFR pt. 355, App. A.

[88] CERCLA, 42 USC § 9659; EPCRA, 42 USC § 11046(a).

[89] See generally Air Emissions, *supra* note 5.

[90] John Thorne and Richard Schwartz, Settlement Confidential (Outline for a Possible Livestock & Poultry Monitoring and Safe Harbor Agreement), 11 June 2002, http://www.sierraclub.org/pressroom/cafo_papers/safe_harbor_proposal.pdf (last visited 11 Oct. 2003).

[91] US EPA, Consent Agreement and Final Order, CAA-HQ-2003-XX (10/09/03 Draft), http://www.sierraclub.org/pressroom/cafo_papers/2003sept_amnesty_agreement.pdf (last visited 31 Oct. 2003).

AFOs. Under the draft agreement, each participating AFO will pay a civil penalty of $500 and contribute $2,500 to implement a nationwide monitoring program for AFOs. Each participant must also make its facility available for monitoring, but it is likely that relatively few facilities will actually be monitored. A monitoring contractor (an independent third party) will conduct the emissions monitoring program according to a plan and submit regular reports to the EPA. Monitoring must be completed within two years, and emissions to be monitored are particulates, ammonia, hydrogen sulfide, volatile organic compounds, and nitrogen oxides. The agreement is intended to reach large AFOs, but any size AFO may participate.

In exchange for participation, the EPA will agree not to sue facilities for failure to comply with certain CAA permit requirements, CAA obligations triggered by emission thresholds, and required reporting under CERCLA. After EPA publishes methodologies for estimating emissions, however, facilities must comply with CAA requirements, install emission controls if necessary, make reports required under CERCLA, and abate nuisances caused by the facility. Moreover, facilities agree not to contest emission-estimating methodologies developed through monitoring in defense of an enforcement lawsuit. The agreement imposes other obligations on facilities that participate. It does not prevent states from enforcing their own laws.

Both members of the environmental community and state and local air pollution administrators have expressed strong objections to what is characterized as a grant of "retrospective and prospective immunity from liability" for every AFO in the United States.[92] Environmental groups object to the fact that the safe harbor policy would exempt AFOs from obtaining permits required by the CAA and that it might interfere with citizen suits filed to enforce the CAA.[93] Moreover, the safe harbor would delay the abatement of AFO air emissions that pose significant health consequences. Air pollution administrators asserted that participating AFOs would receive a waiver of enforcement that applies retroactively, during the monitoring period, and perhaps forever. (The October 2003 draft includes a two-year monitoring program, which may weaken this objection.). Moreover, the waiver would be broadly defined and would include SIP provisions that govern source emissions. Fewer than one percent of the facilities that receive a waiver would be monitored, which could result in limited or unrepresentative data. Further, participants would not be required to adopt BMPs.[94]

No final agreement has been reached, and negotiations continue. Before the safe harbor is implemented, the document should be published in the Federal Register, with opportunity for public comment. But litigation over the proposed agreement has already begun. In September 2003, environmental groups filed suit against the EPA in the US District Court for the District of

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[92] Brent Newell *et al.* (representatives of six environmental organizations), Letter to Christine Todd Whitman, EPA Administrator, 5 May 2003, http://www.sierraclub.org/pressroom/cafo_papers/coalition_letter_to_Whitman.pdf (last visited 11 Oct. 2003)

[93] Some fear that a safe harbor would prevent the litigation of Sierra Club v. Tyson Foods (W.D. Ky), which asserts that Tyson is responsible as an operator under CERCLA for toxic releases at farms of contractors. EPA Eyes Dialogue with States in Wake of Criticisms of CAFO Plans, Insideepa.com, 16 May 2003.

[94] Eagan & Garvey, *supra* note 79.

Columbia, alleging that the EPA violated the Freedom of Information Act by failing to disclose documents about the proposed agreement.[95]

EQIP Funding for Livestock Producers

Federal financial assistance is available to help livestock producers meet air and water quality requirements under the CAA, the CWA, and other environmental laws. The Environmental Quality Incentives Program (EQIP) was enacted in 1996, in part to help livestock and other producers comply with federal and state environmental regulations. In the 2002 Farm Bill,[96] Congress reauthorized EQIP through 2007 and increased authorized funding significantly.[97] USDA's Natural Resources Conservation Service (NRCS) administers EQIP; NRCS published final regulations for EQIP in May 2003.[98]

EQIP is intended to help producers meet environmental quality criteria, to provide assistance to install and maintain conservation practices, and to streamline conservation planning and regulatory compliance.[99] EQIP focuses especially on "beneficial, cost effective changes to . . . nutrient management associated with livestock."[100] The program helps producers to comply with regulatory requirements for soil, water and air quality, wildlife habitat, and surface and ground water conservation. Under NRCS regulations, reduction of various types of nonpoint source pollution is first priority; second priority is reduction of emissions of regulated air pollutants.[101]

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[95] Sierra Club et al. v. US EPA, (D. D.C.). Activists Sue EPA over Draft 'Safe Harbor" for Agricultural Pollution, Insideepa.com, 26 Sept. 2003. Both the FOIA request and the subsequent denial are available at http://www.sierraclub.org/pressroom/cafo_papers/.

[96] Farm Bill, *supra* note 4. The Conservation Title reauthorized and amended a number of conservation programs, including EQIP, enacted in prior agricultural legislation.

[97] EQIP is now part of a program now called the Comprehensive Conservation Enhancement Program; under prior law, it was part of the Environmental Conservation Acreage Reserve Program. $1.3 billion is authorized in fiscal 2007.

[98] 68 Fed. Reg. 32337 (2003), codified at 7 CFR Part 1466. Funding is from Commodity Credit Corporation.

[99] 16 USC § 3839aa.

[100] *Id.* § 3839aa(4). In contrast to EQIP, federal money is not available for animal waste facilities under the Conservation Security Program (CSP), enacted in the 2002 Farm Bill, which pays producers to adopt or maintain conservation practices that help to protect or improve the quality of soil, water, air, energy, plant and animal life, and for other conservation purposes. The statute specifies that payment may not be made for "construction or maintenance of animal waste storage or treatment facilities or associated waste transport or transfer devices for animal feeding operations." *Id.* § 3838c(b)(3)(A).

[101] These include, e.g., particulate matter, nitrogen oxides (NO_x), volatile organic compounds, and ozone precursors and depleters. 7 CFR § 1466.4(a)(1), (2). The other two national priorities are reduction in soil erosion and sedimentation from farmland and conservation of habitat for at-risk species. *Id.* § 1466.4(a)(3), (4).

To achieve these priorities, EQIP authorizes contracts, lasting from one to 10 years, with producers who agree to implement eligible environmental and conservation practices in exchange for cost-share and incentive payments, as well as technical assistance.[102] "Practice" is defined as structural practices (including animal waste management facilities), land management practices (including nutrient and manure management), and comprehensive nutrient management planning practices.[103] In determining the amount and rate of incentive payments, "great significance" can be given to a practice that promotes "residue, *nutrient*, pest, invasive species, or *air quality management*."[104]

The 2002 Farm Bill makes more EQIP money available to livestock producers; it targets 60% of program funding, measured at national level, for environmental practices relating to livestock production.[105] Livestock producers throughout the United States are eligible, and even large facilities may qualify for payments for construction of waste management facilities. A livestock producer whose plan of operation includes an animal waste storage or treatment facility is eligible for cost-share payments if, along with other requirements, that producer develops and implements a comprehensive nutrient management plan.[106]

Conclusion

In recent years, the legal climate for livestock producers has changed. Concentration in the livestock industry has resulted in large facilities, often with accompanying increases in emissions to water and air. Regulatory changes have imposed additional obligations on producers and may increase production costs. Moreover, in some states, suits have been filed against large producers to compel compliance with environmental laws, and neighbors have sued to abate odor and other nuisances.

Livestock producers can help to avoid legal controversy by seeking competent technical advice and following legal requirements. It is important, for example, to choose an appropriate location for the facility, obtain proper permits under federal and state law, comply with set-back and numerous other state law requirements, and follow appropriate nutrient management practices.

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[102] Payments to an individual or entity are limited to $450,000 for all contracts entered during fiscal years 2002 through 2007. Beginning in fiscal 2003, EQIP payments may not be made to an individual or entity whose average adjusted gross income for the previous three years exceeds $2.5 million, unless 75% of that income came from farming, ranching, or forestry. NRCS, Environmental Quality Incentives Program. Fact Sheet (June 2002); see 7 CFR § 1466.24(b)(7) and 7 CFR part 1400, subpart G.

[103] 16 USC § 3839aa-1(5); 7 CFR § 1466.3.

[104] 16 USC § 3839aa-2(a), (e) (emphasis added).

[105] 16 USC § 3839aa-2(g); 7 CFR § 1466.8(d).

[106] 16 USC § 3839aa-5(a)(3); 7 CFR §§ 1466.9(c), § 1466.21(b)(3)(iv). The producer may also be eligible for incentive payments to encourage development of the plan. 7 CFR § 1466.23(b).

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